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PUBLISHER'S COLUMN

NEW YEAR

With this issue **CONTROL** is into its second volume. We have come a long way since last July and learned a good deal about the way control engineers like their material presented. Regular subscribers have probably noticed that from time to time we have introduced new features and given others a new look. This is as it should be—no really live publication remains completely static. As the field widens and more infoımation on new topics becomes available, the magazine has to adapt itself to carry them.

So the occasion of our half birthday seemed a good time to have an overall look at **CONTROL**—in fact, to have a spring clean. We had a meeting of the editorial, production and art departments which lasted for several hours, and the results are incorporated in this issue.

It may be that you think the appearance of a magazine is secondary, that what matters is what the words say, not how they are arranged on a page or the type face used for the headings and titles. Although we certainly agree that the most important part of the magazine is its content, we firmly believe that the art department can make it much easier to read and more pleasant to look at—as well as simpler to find your way about in. This is, of course, especially important for someone seeing the magazine for the first time—he must be able to see at a glance what every article and news section is about. But in our opinion this also has an effect—perhaps subconscious—on the reader who sees the magazine every month.

From time to time we are accused of 'looking American'. While we take this as a compliment, because on the whole transatlantic publishers make a much better job of producing lively-looking technical magazines, we think it is an unjustified one. Nevertheless, we believe that British technical publishing could do with a facelift and we will continue to do everything possible to bring it about.

SIR! LETTERS TO CONTROL

The Editor welcomes correspondence for publication

Scope for reflexion

SIR: In Mr Farrar's review (November) of the American 'Missile Engineering Handbook' he states, 'The "reflectinga rea" used in the radar range equations (Section 6) differs fundamentally from the British definition.'

In the book it appears that the echoing area is defined by the same range equation as is customary in this country. On the basis of the definition given in the reference the effective echoing area of a sphere is calculated to be πa^2 (when $a \gg$), and this is exactly the figure reached from our own theory.

We are particularly interested in this problem, since, in examining performance data on American radars, the target echoing areas quoted seem extremely small, and we have in fact looked (without success) for a difference in the echoing area definition.

English Electric, Luton Airport J. D. HOWELLS

● *Mr Farrar comments*:

'I am glad that Mr Howells confirms our own experience that American square meters appear to be of a different size from British ones. I agree that the American definition of effective echoing area uses the same equation as UK practice does.

'It, therefore, seems that the discrepancy can be resolved only by considering in more detail the nature of the radiation incident on, or reflected from, the target. A practical radar receiver does not usefully collect all the reflected radiation which would be incident on it (e.g. because of polarization loss) and researches by Mr J. A. Robinson of Ferranti Ltd indicate that some American practice is to include this loss with the echoing area rather than in the receiver losses.'—EDITOR

Begin at the bottom

SIR: I have great sympathy with Mr Plane's view (December) that some articles in CONTROL should appeal to the smaller business. This point can indeed be developed further. The specialist in one field is an outsider in many others. Given *time*, of course, he can approach the frontiers of knowledge in another branch of learning, but if he does so he loses his first specialty. Thus the specialist needs articles whose main points he can readily and *quickly* assimilate. These are just the kind which appeal to the smaller businesses—particularly, I think, when they are installation stories. You do not need to know how to groom a horse until you decide to acquire one, but the decision itself is based on what you might use it for. L. LANDON GOODMAN

Electrical Development Association

Need advertisements be waffle?

SIR: Our first reaction on reading Mr Cazaley's letter (November) was that it was a cry from the wilderness and did not need a reply. But your own comments, although effectively answering many of your correspondent's criticisms, do contain a suggestion that there is 'more than a grain of truth' in his arguments.

May I cite the example of the West Instrument advertisement, printed alongside Mr Cazaley's letter. This advertisement contains some of the features he so dislikes—'funny little men', occasional bold type, and limited copy. We designed it to outline instrument features for those engineers who have not as much time as Mr Cazaley to wade through a solid mass of des-

Continued on page 45

SIR!

Continued from page 42

criptive copy. It has the little men to bring a glint of humour to the roving eye (and, incidentally, catch even the eye of Mr Cazaley). It states eight important technical points in a few inches of copy and it tells the reader how he can get a representative along to discuss the instrument in relation to his own plant.

But the inescapable proof that 'pukka engineers' like this approach lies in the response it evokes.

Kingham Advertising Agency, London N. G. DIX

Valves slip

SIR: The December *Industry's Viewpoint* poses a very pertinent question 'Why not British?'. *Control Survey* in the same issue covering pneumatically-operated diaphragm control valves notes 'that the four largest ranges are of American origin'.

May I, on behalf of this British company, point out that we have for 35 years been making high grade diaphragm-operated valves, and that for a large part of this period we have manufactured pneumatically-operated diaphragm valves. As pioneers in this field in this country we think that we might have merited at least a mention in your Survey in what, up to now, we had regarded as an excellent publication.

British Arca Regulators B. F. SHILSTONE

● *Sorry! We tried a number of authorities, including the relevant manufacturing associations, but they did not give us your firm's name. Others missed out were Audley Engineering Co (Domotor-operated control valve) and Meynell and Sons (Rayon-Patent valve originally developed in the Netherlands). Also Honeywell Controls market valves produced by a subsidairy in Germany.* —EDITOR

A clear answer?

SIR: Mr May's views in his letter (October) have, with one exception, my complete support. I do not consider the issue he raises was ever controversial.

The system engineer has no single answer at the present time—he tries to choose, from all available forms of equipment, components most suited to the solution of his problems, not the least of which is economic. The role of automatic control is however changing in concept—it will soon no longer be sufficient for a control system to act merely as an automatic operator guided by preset conditions based on human experience. A process control system will be required to learn and optimize itself; to carry out logical switching and sequencing of events in a variety of circumstances; to modify its own programme to achieve the best performance; to provide high speed monitoring of important variables; and to print out relevant economic data for subsequent automatic analysis. This can only be done electronically, and the conversion of pneumatic inputs to electronic and *vice versa* introduces unnecessary links in the chain with added unreliability.

One cannot, furthermore, discount the cost of providing compressed air and its attendant piping—the complexity of installation of air lines and the difficulty of finding a leak. Finally, it is significant that the users of electronic computers have found that the least reliable elements are those of a purely mechanical or electromechanical nature. Electronics offers precise high-speed operation at greater reliability and lower installed cost than any other means, and it is in this direction that the future of control lies.

Sperry Gyroscope Co D. BURNS

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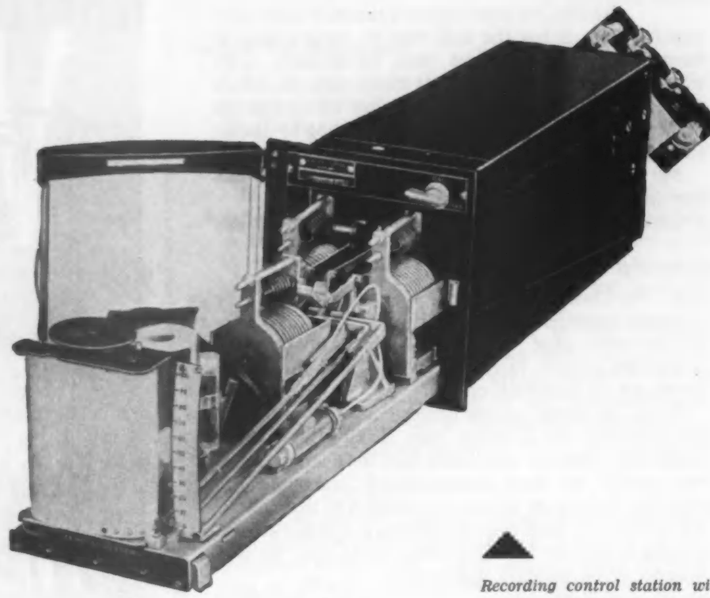
A miniature pneumatic recorder



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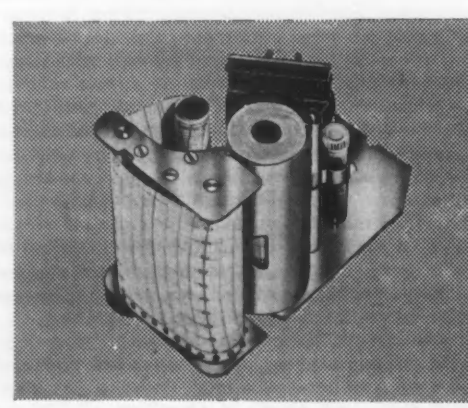

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Quickening the pace

ANYONE IN TOUCH WITH INDUSTRIAL ACTIVITY who pauses at the start of 1959 to think about British industry must be conscious of impending changes. As new scientific developments stream from the world's laboratories, industry is engaging in the preliminary skirmishes of a new revolution, and the potential for rapid advance in modernization is indeed high. But will it be rapid enough?

For this wealth of scientific development brings its dangers. The intelligent industrialist, whether scientifically trained or not, can become dulled to the impact of new engineering researches. He may lose his sense of inquiry. Unless he sees an immediate connexion with his own work, he can shrug his shoulders at each new scientific announcement and murmur 'Interesting, but not for me. The world may be changing, but not my work'.

When this ostrich attitude is found—as all too often—among company directors and managers it spells trouble. Why? Because however healthy Britain's trade is in this present period of lull, her underlying economic position is precarious. Most of us living in these overpopulated islands have seen enough economic crises since 1945 to appreciate this. As the chill wind of trade competition, from Germany, Japan, France and Russia, blows fiercer in the nineteen-sixties, we shall need to raise our industry to peak efficiency to maintain—let alone, raise—our standard of living.

Some three years ago the concepts of 'automation' were thrust before the British public in a blaze of publicity. Many people have written and spoken much nonsense about it and its consequences. But the kernel of the new concepts is undoubtedly the use of feedback and of computing equipment to relieve man's brain as against the use of instrumentation and mechanization alone to relieve his senses and his muscles. Terms like 'full automation' have now come in to stress this aspect. Yet we in Britain are still far off achieving fully automated manufacture. Unfortunately the confusion over the meaning of 'automation' has allowed many people to play down the new ideas as not being really new and to shut their eyes to the coming upheaval in industrial practice. In general, industrial management has failed to make good use of the last three years in paving the way for 'full automation'.

Financially this does not matter at present. A fully autocontrolled factory for making, say, a fairly simple consumer product such as a fountain pen would almost certainly not be economic for some years. But we now have the engineering techniques to build and operate such factories successfully, and they will soon become a necessity for Britain, if only because *other exporting countries will apply and improve the techniques and make autocontrolled factories economic*. Thus we have no time to waste.

Given more demand among industrial leaders, pilot plants for autocontrolled factories might be established now. With them Britain could gain experience of computers in control of machining, inspection, handling and assembly. But such plants would initially be very expensive and the Government should take the initiative. They could develop and build a state-owned automatic factory or allocate funds, perhaps through the National Research Development Corporation, to private industry to carry out the necessary work.

Coupled with the need to press on with technical development of 'full automation' is the need to inform management of its capabilities and its usefulness. In *Industry's Viewpoint* this month Mr Vorlander discusses one important way of doing this—the case history. More formally, there is a need for an educational drive. Short courses on 'full automation', held in industrial centres for business executives, would be most valuable.

So far British Governments have done little about automation beyond issuing a DSIR report two years ago, sponsoring some research and development on individual projects and revealing the results of a Board of Trade inquiry earlier this year. What is now needed is fuller and more positive encouragement to industry, since in modernization of industry lies our economic hope for the future. Britain will almost certainly have a Minister specifically responsible for industrial production within a decade. It is not at all too soon to appoint one now.

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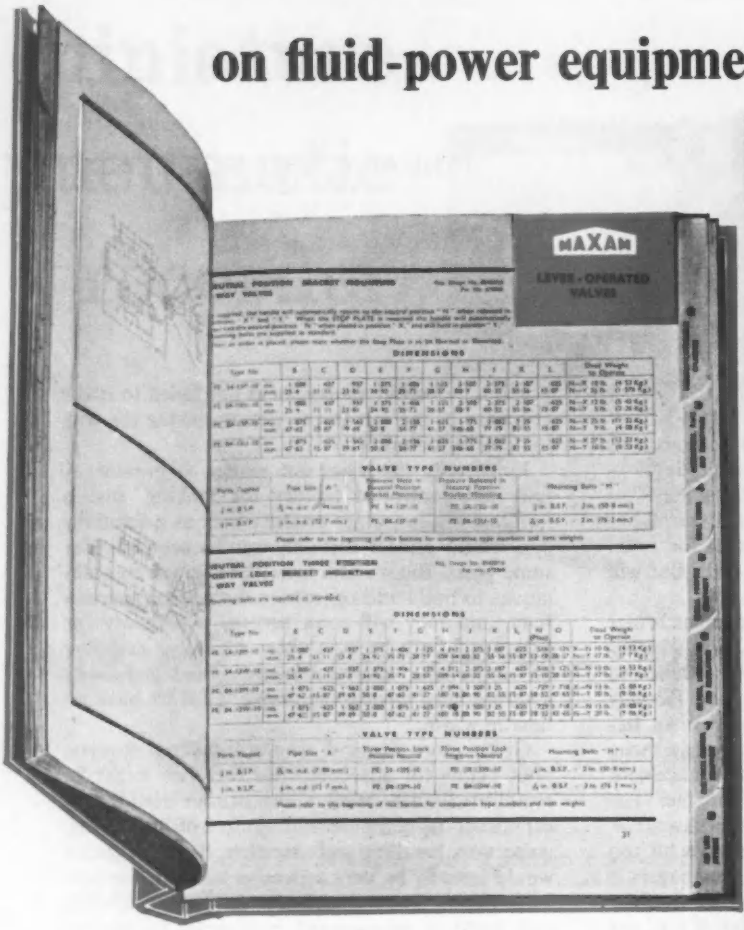

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INDUSTRY'S VIEWPOINT

A monthly article by a prominent man in the control industry on a subject chosen by himself

FROM DRAWING BOARD TO BOARD ROOM

or why management needs control case histories

—explained here by E. C. Vorlander, managing director, Honeywell Controls Ltd

ALTHOUGH THE CONTROL AND INSTRUMENTATION industry has grown phenomenally since the war, an awareness of its capabilities has not yet been adequately communicated from the drawing board to the board room in many user firms. This, in my opinion, is a major factor now limiting wider use of automatic processes in industry.

Continually rising costs and intensifying international competition are requiring the top management of every manufacturing and processing company to explore all possibilities of cost and quality improvement—in an effort to solve the economic equation which will spell tomorrow's success or failure. While many engineers are well aware of the economic and operating benefits derived from today's control systems, the climate for their application can be established only by management at the highest level.

Certainly the incentive exists: already many managements have realized that gains in the efficiency of basic equipment are becoming extremely narrow in relation to investment outlay, and that the only practical means of realizing substantial cost reduction lies in improving the operation of the basic equipment itself.

However, since many company directors have no technical background, they often have only the most general knowledge of what can be achieved by more extensive use of instruments and controls. And since today's sophisticated systems of control frequently involve important financial and organizational considerations, a better understanding in the board room of controls and instrumentation is highly desirable.

Our industry can therefore gain much—and do so in the best interests of British industry as a whole—by presenting management with case histories illustrating, in non-technical terms, the broad concepts of control engineering and the financial and quality benefits to be gained from its application. Here is an actual example of the kind of case history I have in mind. It is drawn from the food industry—an industry in which control engineering could be much more widely applied.

Several years ago a confectionery manufacturer was persuaded to experiment with an automatically controlled production line. The project involved almost two years of intensive work, including pilot operations and the construction of some items of special equipment. Results exceeded the most optimistic expectations. Automatic controls reduced process time from sixteen hours to thirty-five minutes. The automatic production line required only one-third of the floor space needed for the other, manual, lines. Production per man-hour was increased by nearly two hundred per cent. And the product was improved in quality and appearance.

With results like that, it is hardly surprising that the company's management lost no time in having automatic control applied to all production lines. I believe that when that kind of case history becomes common knowledge at board room level, the use of automatic processes in industry will increase rapidly.

E. C. Vorlander

courtesy Alfred Herbert Ltd

Fig. 1 A hopper fed machine which sorts parts into different groups depending upon their dimensions

Automatic inspection is becoming more significant with the spread of automatic manufacture and processing. Here an experienced instrument engineer summarizes its techniques and potential

Replacing the human inspector—1

by **PETER D. ATKINSON, M.A., A.M.I.E.E.**
Measurements Division, Tube Investments Technological Centre

INSPECTION IS PERFORMED IN WORKS AT MOST STAGES OF manufacture; in some it is a thorough and organized operation while in others it is a cursory examination not even recognized as inspection. Part finished work is examined mainly in order to save the cost of processing material which would be rejected at final inspection or which may cause broken tools or other damage to machinery. Final inspection is concerned with ensuring that the product reaches the standard of quality which is required.

The most immediate and obvious use of the results of inspection is to sort parts or material into accept or reject bins. There is also almost always some feedback of information with the object of reducing the number of rejects in subsequent production. This feedback may be an immediate and conscious action such as is involved in setting up or controlling a process, or it may be a much slower procedure involving the study of the effect of changes in production practice on rejection rate.

Inspection basically consists of measuring certain dimensions or parameters of the product and comparing them with the limits of what is acceptable. The measurement can be made by the use of a proper instrument and the reading noted and compared with properly specified limits; or a gauge may be used, this really being a combination measuring instrument and limit comparator. Alternatively the part is merely subjected to a visual examination; no measuring instrument in the normal sense is employed but nevertheless the inspector makes a measurement or assessment of some feature of the part, and compares what he sees with his own version of the standard of acceptance.

The needs of inspection

The growth of automatic manufacturing and processing methods is being followed by the growth of automatic methods of inspection. This is partly owing to the demand for inspection equipment in automatic plant and partly owing to the advantages of automatic inspection equipment in its own right. When automatic manufacturing methods are adopted the needs for inspection change; increased reliance may be placed on the machine because it is not subject to the errors and fatigue of an operator, thus eliminating some inspection operations, while conversely the absence of an operator raises new problems. For example, in an automatic transfer machine it may be necessary to provide a device which will detect a broken drill remaining in a hole, and then stop the machine in order to avoid damage which might be caused if it attempted to tap the hole; an inspection operation of this kind would be unconsciously performed by an operator.

Another example of the special needs of automatic plant is found in automatic assembly machines where a current problem is the frequency with which work is stopped because the machine jams due to components

being outside tolerance; the solution to this problem may well lie in the much greater use of automatic inspection equipment as being the only economic way of eliminating a small proportion of incorrect parts. A further way in which automatic inspection equipment is associated with automatic plant is in the control of processes. Here the inspection device is the means of measuring the controlled quantity.

The incentive to use automatic equipment independently of the special needs of the manufacturing process arises in three main ways: it may lead to a direct saving in labour cost; it may offer improved reliability and consistency because it is not subject to fatigue and loss of concentration; or it may be capable of making a test or measurement which cannot be performed by a human

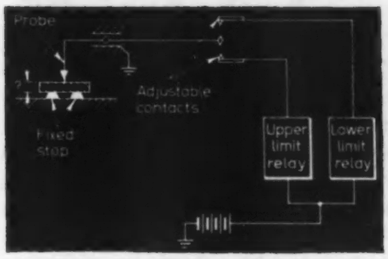


Fig. 2 A common method of inspection. The size of the components will determine which relay is energized

inspector. This type of equipment is most often used because of its technical advantages; direct saving in labour cost is less commonly the justification for the expenditure involved.

Let us now examine the pıincipal considerations which influence the decision to use automatic inspection equipment.

The capital cost of the equipment is almost always greater than that for manual methods. When the manual method depends largely on the inspector and the equipment which he uses is simple, the capital cost of an automatic instrument may be expected to be much higher. But where the measurement is already made by an instrument (the part played by the inspector being mainly to read and adjust it), the additional cost of having an automatic instrument and automatic alarm when the tolerance is exceeded may be comparatively small.

Speed of action

The time required to perform an inspection operation is often important. This may be because it governs the rate at which articles can be inspected and thus determines the number of instruments required for a given production rate. Or where the measurement forms part of a control loop it may determine the speed at which the process can operate, and thus fix the output of a large amount of equipment.

It is generally the case that automatic instruments will do the job more quickly than manual methods; this is owing to the speed with which deviations from requirements are detected and appropriate signals given, for here the high operating speed of electronic circuits can be utilized.

Consistency

A human inspector engaged on a repetitive task is inevitably subject to fatigue and occasional errors due to his attention being distracted. Errors due to these causes arise mainly either where the alertness of the inspector is involved in observing faults in material passing his station continually, or where his judgment is needed to decide whether to accept or reject the work. In either case automatic instruments can show great advantages in reliability and consistency; the advantages gained in this way are among the most powerful reasons for using automatic equipment.

Present uses

In some industries automatic inspection equipment is already in extensive use, although it is comparatively rare for it to be integrated into an automatic transfer line. The gauging of small components to check that the dimensions are within specified tolerance is the most extensive application and is commonly used in industries in which precision components are made at high production rates, e.g. the automobile industry. The machines

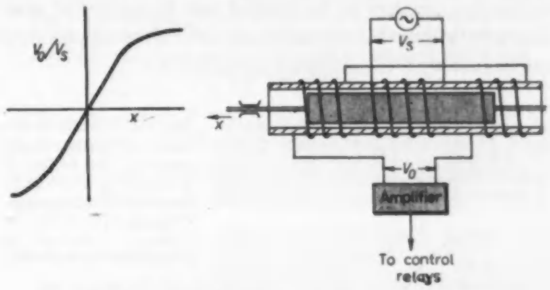


Fig. 3a A linear differential transformer is an example of a device that can give a continuously variable indication

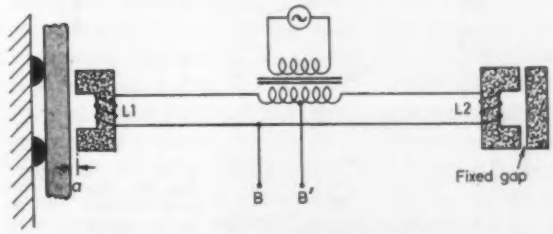


Fig. 3b In this variable inductance gauge there is no contact between the detector and the surface to be measured

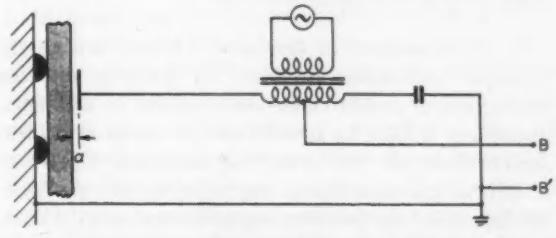


Fig. 3c The variable capacitance gauge also has no contact between the two surfaces

are normally hopper fed and are used either to sort the parts into accept or reject categories, or into a larger number of groups to permit grading or selective assembly (Fig. 1). They are mainly justified by the direct saving in labour and floor space, but they have the added advantage of greater reliability than manual inspection.

During recent years there has been a great increase in the use of automatic thickness measuring instruments on continuous and semi-continuous processes, such as paper making and strip rolling. These instruments are used to give a warning of excessive thickness variation or to provide signals required for closed-loop control of the thickness. The use of such equipment has made it possible to achieve substantial improvement in the dimensional control of the product, and consequently a reduction in the amount of scrap. Even in processes which are inherently stable, a rapid and accurate control of this nature can be most valuable when starting up or when resetting for a different size.

In flaw detection great progress has been made in the last 10 years on the basic flaw detecting and measuring techniques and in instruments which will operate automatically. However good the instrument, if it is manually operated it is dependent on the 100% alertness of the operator. Increasing use of automatic flaw detecting equipment appears to be limited less by economic considerations than by the technical difficulties of devising equipment with the required performance.

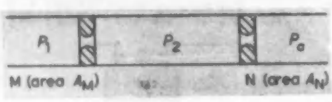


Fig. 4a This shows the basic principle of air gauging. The orifice N is varied by a probe on the surface to be gauged. Pressure P_2 will thus be a direct indication of the probe movements

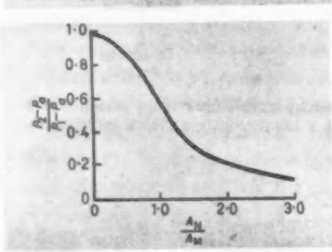


Fig. 4b The relationship between P_1, P_2, P_a and the area of orifice N

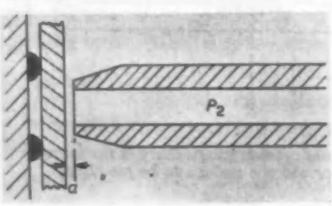


Fig. 4c The non-contact method of air gauging

In the remainder of this article I shall review the principal techniques available for carrying out the measurements and comparisons involved in automatic inspection. It must be stressed that in addition to these aspects there are two other considerations which are often involved in automatic inspection operations. These are the mechanical handling required to present the work to the measuring instrument, and the processing and recording of the test results.

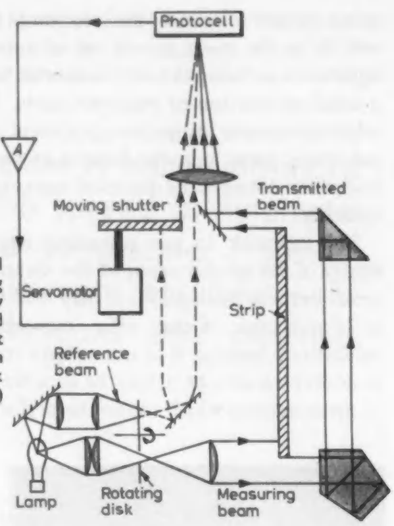


Fig. 5 An optical method of measuring the width of narrow strip. (The dotted line indicates that the reference beam is cut when the disk is in this position)

Dimensions

Measuring dimensions involves determining the distance between specified points on certain surfaces. There are two basically different ways of doing this. The more common way is to find the position of the points whose separation must be measured, either with reference to a fixed datum, or the one with reference to the other; e.g. measurement by micrometer. The second way is to find the thickness of material between the surfaces in terms of some property of the material; an example is the determination of the length of a piece of wire of known diameter by measuring the electrical resistance. Methods which depend on the thickness effect require more complex apparatus but they are useful where only one surface is accessible, or where it is necessary to avoid contact, for example because the material is hot.

Surface methods—1

Mechanical. For automatic measurement the basic problem is that of converting linear displacement into electrical or other form suitable for transmission away from the inspection point. An exception to this is found in some 'go' and 'no-go' gauges which automatically divert the parts into different chutes depending on their size. Here the measurement and comparison functions are combined. Purely mechanical methods of this kind are restricted in their application because they can be used only for components of suitable shape, and each one must be designed as a special.

Surface methods—2

Electrical. The usual way of applying a displacement measuring device to inspection is indicated in Fig. 2. The part is held with one of the defining surfaces registered against a fixed stop, the transducer being used to determine the distance between the fixed register and the tip of the probe. The simplest type of transducer used for this work consists of an extremely sensitive limit switch shown in the same figure. The adjustable contacts are so arranged that when the dimension in

question is within tolerance neither is closed. If the upper or lower tolerance is exceeded one of the contacts is made and current flows to energize a relay. This relay operates selector mechanisms in the mechanical handling gear, causing the rejected part to be diverted into an appropriate container. These switches are made in a range of sensitivities; types which can detect movements as small as 0·000 05 in. are available. As might be expected these very sensitive detectors have a limited range of adjustment, and if a large range of tolerance is required less sensitive switches must be used.

This type of detector forms a convenient basis for building special-purpose gauging stations for checking a large number of dimensions on a single part. They have the advantage of being simple, and they do not need electronic amplifiers to couple them to control equipment. They have two inherent limitations; they cannot give a continuously variable signal proportional to the dimension gauged, and they cannot be used to grade parts into more than three categories.

The need for a continuously variable indication arises in the gauging of work during a process, where it is required to record automatically the profile of a part, or for sorting by size into more than three categories. For such duties electromagnetic transducers are widely used since they are simple, robust and sensitive. In these the movement of the probe causes either a change in the reluctance of a magnetic circuit or a change in the coupling between two coils. Many different designs have been used: one example is the linear differential transformer in Fig. 3a.

The electrical methods discussed so far have involved mechanical contact between the detector and the surface to be gauged. Methods are available which depend on measuring the air-gap between the surface to be gauged and a fixed probe. In Fig. 3b the principle of electromagnetic gauges of this type is illustrated. Change of the air-gap dimension a changes the inductance of the coil L1; thus the bridge unbalance voltage at terminals BB′ is a direct indication of the gap a and hence of the dimension required. A similar method in which the electrostatic capacitance between the part and a fixed probe is used as indication of the gap dimension is shown in Fig. 3c.

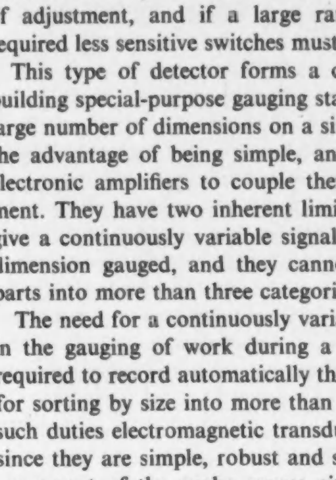
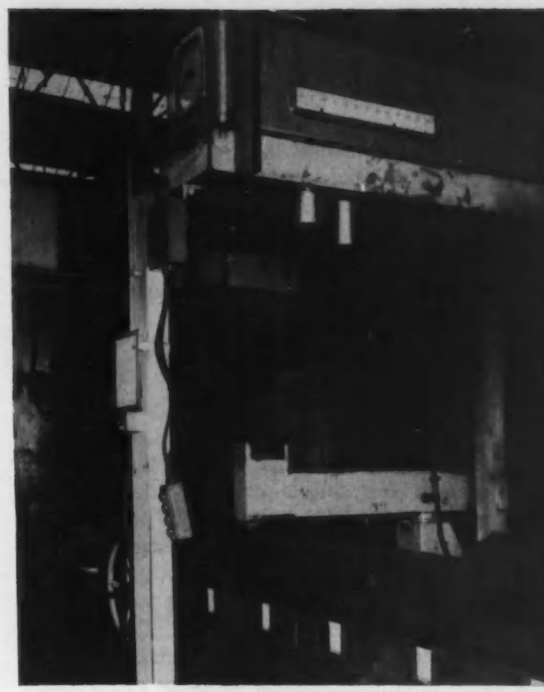


Fig. 6 One of the edge-followers for an optical method of gauging the width of wide strip



courtesy Davy and United Engineering Co Ltd

Fig. 7 A wide strip meter and radiation thickness gauge in use on a hot strip mill. The two tubes pointing downwards are the edge followers, and the nominal width is indicated on the dial at the end of the box

Surface methods—3

Air gauging. Compressed air has long been used in semi-automatic gauging for the same purpose as the electromagnetic transducers described above (*1*). The basic principle of these gauges is illustrated in Fig. 4. In Fig. 4a the orifice M is fixed and the orifice N is variable. The relationship between P_1, P_2, P_a and the area of orifice N is as shown in Fig. 4b. To make practical use of this, P_1 is obtained from a constant pressure supply, P_a is atmospheric pressure, the orifice N is controlled by the movement to be measured and P_2 is a direct indication of that movement. Two methods of relating the orifice size to position of the surface to be gauged are used. In the first a probe makes contact with the surface and movement of this probe varies the opening of a valve. In the second and simpler method (Fig. 4c) the clearance between the surface and the gauging probe controls the orifice. Advantages of the latter method are that contact with the surface is avoided, and that the action of the air jet is to clear the surface of particles of dirt and swarf which might render a contact gauge inaccurate. Typical sensitivities of air gauge are of the order of 0·000 05 in. It is difficult to achieve a useful working range of more than about 0·004 in. An important advantage of air gauging over electromechanical methods,

when used as an indicating instrument, is the simplicity and stability of the associated equipment: a water gauge is used to indicate pressure and electronic amplification is not needed. These advantages are less significant where automatic gauging is required because an output in electrical form is almost always needed; thus some form of pneumatic-to-electrical transducer must be provided. For automatic inspection electromechanical methods appear to be generally more suitable, except in cases where the special advantages of self-cleaning and contactless operation of air gauging are important.

Surface methods—4

Optical. Use of light beams to determine the position of the surfaces makes it possible to effect dimensional gauging with a large clearance between the work and the instrument. Instruments originally developed by BISRA and now available commercially provide good examples of the ways in which high accuracy can be achieved. They were designed for the gauging of steel strip during hot rolling, but the principles are applicable to other similar measurements.

The instrument for narrow strip is illustrated in Fig. 5. A change of strip width causes a change of the beam area remaining after the double transit but a movement of the strip in, or normal to, its own plane does not alter the area of the transmitted beam provided that both edges still cut the light. The measuring beam and the reference beam are chopped by a rotating disk so that light from each in turn falls on a single photocell. The alternating output voltage from the cell is thus a measure of the difference in intensity of the two light beams. The reference beam is masked by a moving shutter which is driven by a servomotor to reduce the photocell output to a minimum, and thus the position of the shutter is a measure of the area of the measuring beam and hence of the width of the strip. Because the photocell is only a null detector, variations in its performance and that of the light source do not affect the accuracy which depends mainly on uniform intensity of the measuring and reference beams and on the cleanliness of the optical components, particularly the four windows through which the measuring beam passes. In the prototype instrument a strip of the order of 5 in. wide, and having a width of $\pm \frac{1}{8}$ in. and a permitted lateral movement of $\pm \frac{1}{4}$ in. could be gauged with an accuracy of $\pm 0{\cdot}005$ in. Speed of response depends on the servomechanism, a response time of about 0·1 sec can be provided without difficulty.

The instrument for wide strip depends on the light radiated by the red hot material (*2*). It comprises two edge-following devices separated by the nominal width of the strip. The principle is illustrated in Fig. 6, which shows one edge follower. The slit in the moving shutter is moved by the servomotor to maintain equal light energy on each photocell. Thus movement of the shutter is a measure of the deviation of strip edge from its nominal position. By summing electrical signals proportional to the shutter movement in the two followers a signal proportional to the deviation from nominal width is obtained. The instrument is largely independent of variations in strip temperature over a wide range because the strip itself is the source of the reference beam (Fig. 7). The accuracy depends on the range of variation of width to be accommodated with one setting and the lateral movement to the strip allowed; for a width range of ± 1 in. and a lateral movement of $\pm 1\frac{1}{2}$ in. the accuracy of width measurement is $\pm 0{\cdot}03$ in. and the response time 5 sec.

Thickness methods

A number of physical effects have been successfully used for the measurement of thickness. It is important to remember that they all depend on some property of the material in such a manner that an undetected change in that property must cause an error in the measurement. Thus the choice of method, and the results obtained, depend greatly on the particular application in question. Space does not allow an exhaustive review of all the methods but the more important ones are discussed below.

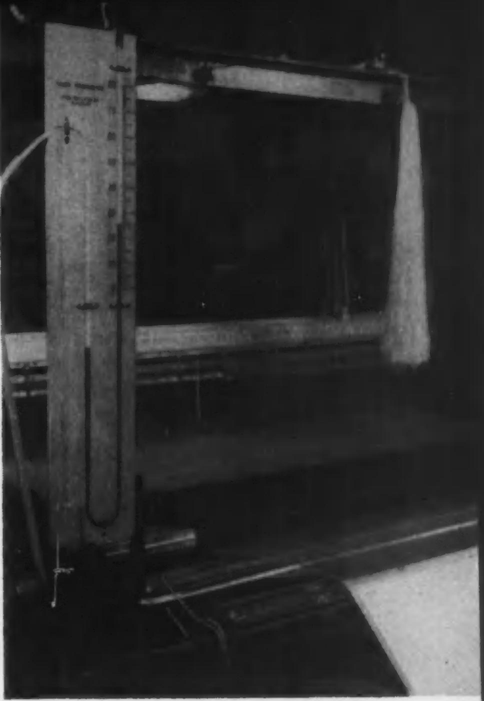
Electrostatic capacitance

The electrostatic capacitance of two conducting sheets separated by a fixed distance depends upon the dielectric constant of the material between them. If the distance between the plates is filled partly by air and partly by a layer of insulating material, then the capacitance depends upon the thickness and the dielectric constant of the insulator. This effect is used to measure the thickness of materials which are insulators. The advantage of the method is that the electrodes need not come into contact with the surface of the material, thus for example plastics sheet and sections can be gauged in manufacture while still soft.

There are two main difficulties in using this method of gauging. First, variations in the dielectric constant of the material can cause errors in the measurement. The importance of this aspect depends on the accuracy required in the measurement and on the raw materials used; it may be necessary for example to check the calibration at fairly frequent intervals or to adjust the instrument each time a new batch of raw material is started. The second problem is concerned with the instrument itself. In most practical cases the area of the electrodes is such that the capacitance to be measured is of the order of a few micromicrofarads and represents only a small part of the total capacitance in the circuit. This additional capacitance is due to the cable connecting the electrodes to the electronic equipment and also to capacitance between the electrodes and earth. The difficulties due to these unwanted capacitances can be reduced by careful layout of the electrodes and the connexions, and by using a transformer bridge circuit (*3*).

To be continued

Textile control —a picture guide



The dyeing and finishing sections of the textile industry, operating small numbers of highly productive and expensive machines, have problems in common with certain branches of chemical engineering. In these sections instrumentation and automatic controls are both appreciated and easy to apply. In contrast, the yarn spinning and fabric manufacturing sections tend to operate units of large numbers of similar machines, and some automatic controls proposed cost more than the machines themselves, for the problems are specialized. However the range of economic applications for autocontrol has recently been growing fast, and will undoubtedly continue to do so.

GLOSSARY

BEAM A large flanged warp bobbin on which several thousand threads are wound in parallel.

CARDING The process whereby a lap is converted into a sliver, the fibres being individually separated in order that the final traces of impurity may be removed.

CHEESE A cylindrical flangeless bobbin.

CONE Similar to a cheese but tapered in order to facilitate yarn removal.

LAP A roll of fibre the width of the processing machine.

SCUTCHER The last machine in a line of beaters for loosening matted fibre in order that particles of dirt may be removed pneumatically.

SLIVER An untwisted continuous rope of fibre.

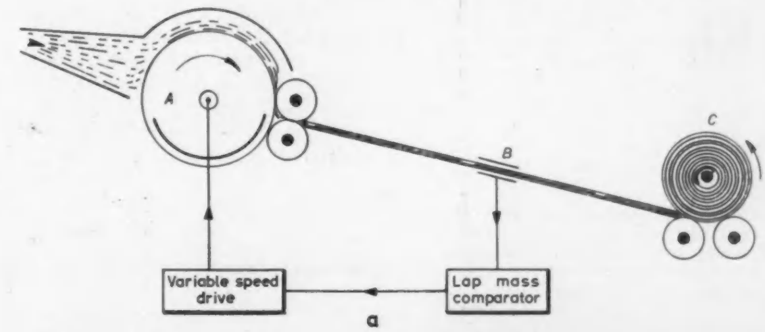
VISCOSE STAPLE Filament viscose rayon which is cut in order that it may be processed on conventional cotton and wool spinning machinery either alone or in blends.

by **DAVID BRUNNSCHWEILER**

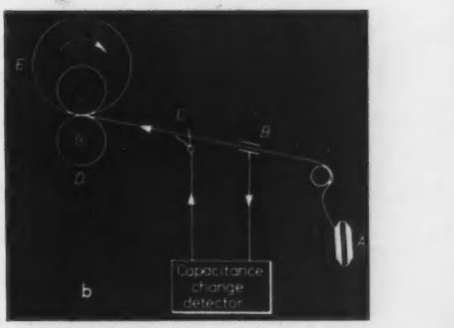
Department of Textile Industries, Manchester University

I—Controlling lap and yarn evenness in cotton and viscose staple spinning

a On the scutcher, loose fibres are pneumatically collected to form a lap, which is batched to act as a supply for the carding process. Control of lap density determines the regularity of the material at succeeding processes. Normally, batched laps of known length are weighed and allowed to pass if the weight lies between predetermined limits, but continuously reading capacitance mass measuring instruments are now being fitted to the scutcher, using the fibre lap as a dielectric. Automatic speed regulation of the collecting drum and feed rollers, governed by the mass measuring instrument, is available experimentally, although most commonly the relatively infrequent adjustment required is made manually at the present time.



(*Above*) **Lap former:** *A* Pneumatic collecting drum; *B* Capacitance pick-up; *C* Lap batching roll. (*Right*) **Cone winder:** *A* Spinning bobbin; *B* Capacitance pick-up; *C* Solenoid actuated yarn cutter; *D* Driving roller; *E* Yarn cone



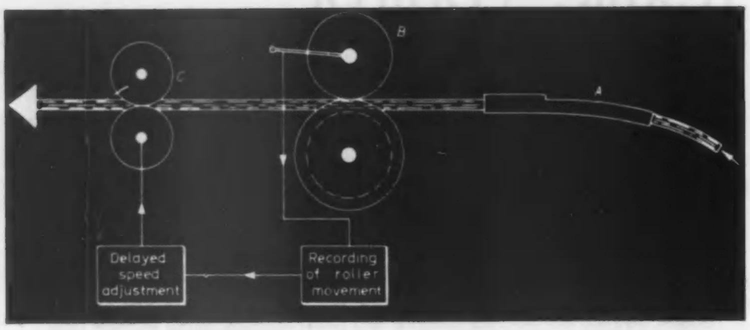
b Capacitance methods are also now being used to detect unwanted thick places in yarn which is transferred at high speed—1000 yd/min—from spinning bobbins onto large cones. If the rate of change of the mass of yarn passing between condenser plates exceeds a preset value, a solenoid-actuated knife cuts the yarn. The thick place is then removed manually, the yarn being knotted by mechanical knotter. Photoelectric methods of thickness measurement are also available, and pneumatic methods have been used experimentally.

It is worth while noting that a spinning mill will probably have a hundred times as many cone winding spindles as scutchers.

2—Automatic sliver regularity control in worsted spinning

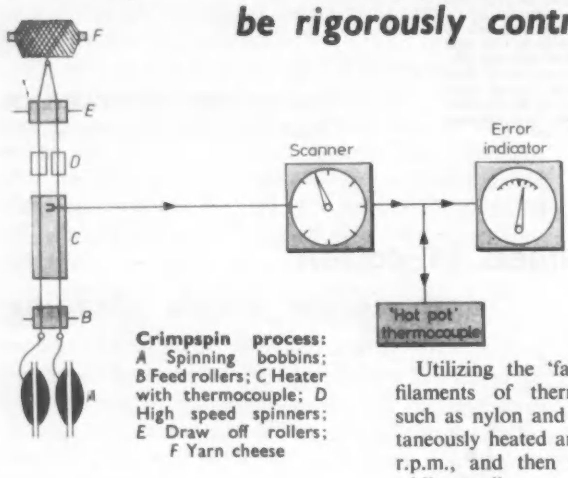
The Raper Autoleveller measures the cross-sectional area of a sliver (i.e. untwisted rope) of fibres by means of a presser roller compressing the sliver into a matching grooved roller. The thickness variation is recorded mechanically as a pattern line in a relay mechanism which then makes the necessary speed adjustment to the feed rollers at the moment when the appropriate portion of the sliver is passing through. The Autoleveller gives considerably improved material regularity with fewer processes.

Operating with a coarser, longer and more expensive raw material, such individual speed control units are economically justified during worsted processing much more than with cotton.



Raper Autoleveller: *A* Sliver entry guide; *B* Thickness measuring roller; *C* Feed rollers

3—Temperature during the crimping of nylon filaments must be rigorously controlled



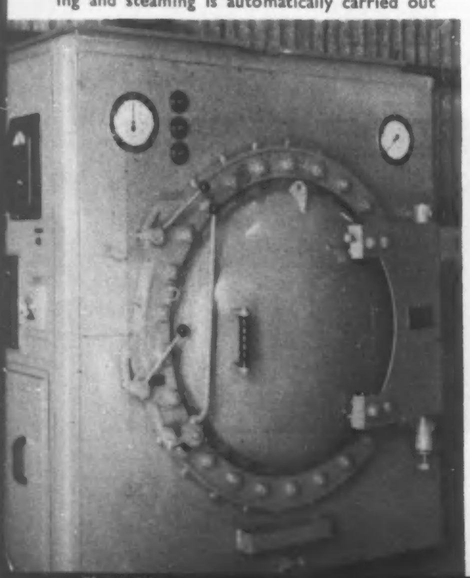
Crimpspin process: *A* Spinning bobbins; *B* Feed rollers; *C* Heater with thermocouple; *D* High speed spinners; *E* Draw off rollers; *F* Yarn cheese

Utilizing the 'false twist' principle, filaments of thermoplastic materials such as nylon and Terylene are simultaneously heated and twisted at 40,000 r.p.m., and then allowed to untwist while cooling to room temperature. This produces a crimped yarn which spirals when relaxed.

Accurate spindle-to-spindle control of the setting temperature is vital, as any variation results in non-uniform dyeing and lustre, producing streaky fabric.

The Scragg Crimpspin machine, fitted with the Fielden Multipoint Temperature Controller and Automatic Monitor, has 120 heating units, each with its own thermocouple. The multi-switch scanner contacts each thermocouple once every 15 min, comparing its output with that of a thermocouple located in a standard 'hot pot'. Should the variation exceed $\pm 1°$ C, the scanner stops, indicating the number of the faulty heater and the degree of error, a warning signal summoning the operator. The heater concerned is then trimmed manually.

A SANDERSON AUTOMATIC AUTOCLAVE used for the setting of single yarns and fabrics. The cycle of operations for heating, pressurizing and steaming is automatically carried out



4—Automatic size boxes ensure uniform application of size to warp yarn

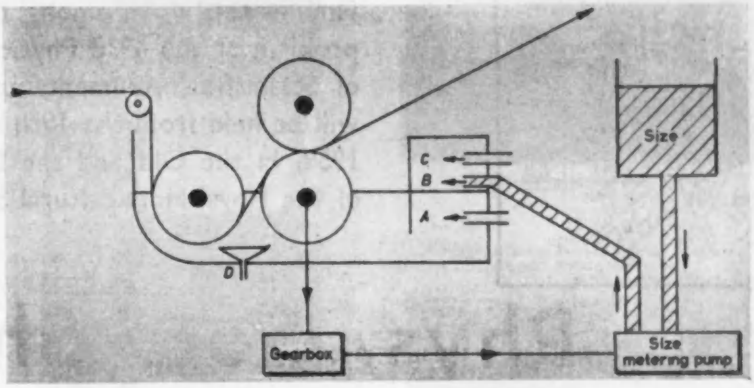
Before weaving, the continuous sheet of warp yarn is coated with a protective starch paste, uniformity of application being necessary. Variations in size viscosity, yarn moisture content and take-up characteristics, and the mechanical conditions of the sizing machine, all affect the uniformity of application achieved. The Shirley* Automatic Size Box, which is self adjusting, allows for all of these factors by delivering the dry ingredients into the size box at the same rate as they are required by the warp passing through, the necessary dilution being provided by steam condensate and the controlled addition of water up to a sensitively regulated level.

If, for any reason, the rate of size take-up by the warp exceeds the required quantity, the concentration and hence the viscosity of the size will fall, and thus the rate of take-up will be reduced until equilibrium conditions are reached. Conversely, a fall in the rate of take-up will increase the size viscosity.

The Shirley system depends upon the

* The trade mark of the British Cotton Industry Research Association.

direct relationship between size viscosity and rate of take-up, and can be applied to any coating process where these conditions exist. Very accurate metering pumps are required, and the box capacity must be small if a rapid response to changing conditions is to be obtained.



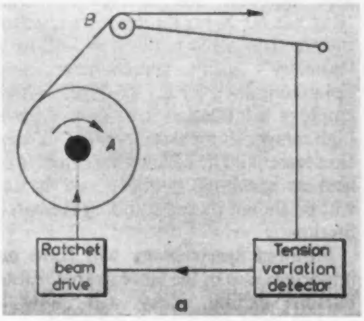
Shirley automatic size box: *A* Continuous live steam supply; *B* Concentrated size supply; *C* Intermittent water supply; *D* Level diaphragm controlling water pump

5—How warp tension and speed during weaving and knitting can be regulated

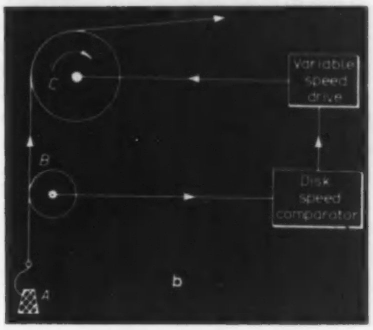
a In delivering a sheet of warp yarn from a beam into a weaving loom or warp knitting machine, either the speed of entry or the sheet tension must be maintained constant. Theoretically, if either of these factors is kept constant, the other will follow, but in practice, variations occur.

On automatic looms, the average warp tension is maintained constant by passing the warp sheet over a spring balanced roller. Any slight variation in the roller position alters the arc of contact of a continuous reciprocating pawl and its ratchet wheel, thus varying the beam drive to correct the error.

b On the warp knitting machine made by the FNF Machinery Manufacturing Co the warp speed is kept constant by means of a variable speed beam drive controlled through a 'slave thread'. This thread rotates a disk, prior to being wrapped completely round the beam and knitted into the fabric together with other threads from the beam. The disk speed is continuously compared (either electrically or mechanically) with the speed of a disk moving at the standard speed, any necessary correction being made to the beam speed.

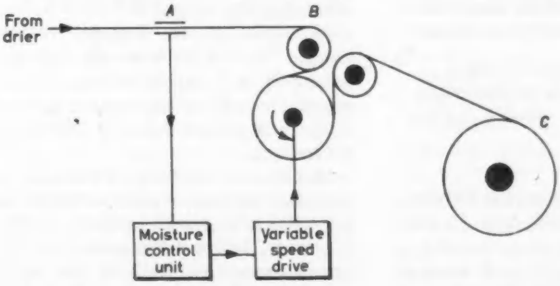


Loom beam drive: *A* Beam; *B* Tension roller



Knitting beam drive: *A* Supply cone for slave thread ; *B* Disk; *C* Beam

6—Winding speed after drying can be controlled by the fabric moisture content



Moisture control unit: *A* Moisture detecting device; *B* Draw off rollers; *C* Negatively driven batching roller.

After wet processing, whether sizing, dyeing or finishing, it is important that the material should be wound at a suitable moisture content. Too high a moisture content encourages mildew, while too low a moisture content is indicative of wastefully slow processing.

Electrical moisture measuring instruments, whether using variations in capacitance, resistance or electrostatic charge, are now commonly fitted, being frequently linked with the speed control of the machine. Thus, if the material is too wet, the processing speed is reduced to provide a longer drying time, and vice versa.

FUTURE TRENDS

- ★ *Re-equipment with very productive but expensive machinery operated by multiple shifts: more instrumentation and control justified economically.*
- ★ *Automatic speed, moisture and temperature controls fitted as standard on dyeing and finishing plant.*
- ★ *In spinning, weaving and knitting, introduction of centralized scanning regulators to spread cost over many machines.*
- ★ *Further development of specialized controls for weight per unit length of yarn, degree of stretch and yarn tension.*

Finding the wood among the trees will be the problem at the 43rd Physical Society Exhibition of Scientific Instruments and Apparatus, which will be held from the 19th to the 22nd January, 1959, in the Old and the New Exhibition Halls of the Royal Horticultural Society, Westminster

Phys. Soc. Show 1959

DESPITE OVERCROWDING, BOTH OF visitors and exhibitors, and accusations that it has become far too commercial, the annual Physical Society Exhibition seems to go on from strength to strength. This year 153 firms and research organizations will exhibit their wares and this preview is presented in the hope that it will help the visitor to the Show, and also enable those who cannot attend to keep abreast of the latest in instrumentation. Tickets for the Exhibition are, as ever, hard to come by, but we understand that a written application to the Physical Society at 1 Lowther Gardens, Prince Consort Road, London, SW7—enclosing a stamped and addressed envelope—will be viewed with sympathy.

General analysis and research

The majority of the equipment to be shown comes within this rather broad classification. Fairey, Mullard Equipment and Newport Instruments will all show equipment connected with **nuclear magnetic resonance spectroscopy**. Fairey's is small and simple and of medium resolution, while Mullard's SL 44 Mark 2 is a recording spectrometer of high resolution (better than 1 in 10^7). Newport Instruments will demonstrate simplicity and economy in n.m.r. equipment.

The Distillers Co will show a **null balance magnetic oxygen analyser** for the analysis of oxygen in flue gas, gas process streams, etc. Measuring the magnetic susceptibility of a continuously flowing sample, it employs a feedback system and is automatic. Detection limits are 0·005% O_2 or 0·25% f.s.d. An electrochemical dissolved oxygen analyser (gas phase transfer type) for the high pressure and temperature systems of modern power stations will be exhibited by Cambridge Instrument Co.

An **X-ray microanalyser** for quantitative chemical analyses of small volumes (about 1 cu micron) will be shown by Metropolitan-Vickers, together with three **spectrometers**: the MS7 double-focusing mass spectrometer of the Mattauch type, primarily for the analysis of impurities in solids; a 2-in. radius mass spectrometer for the laboratory and intended for the direct determination of the composition of gases and vapours; and a Newton-Victor 'Raymax 60' X-ray fluorescence spectrometer. Crystal Structures will show a 'Wooster' X-ray spectrometer, and Solartron their YZ.736 type, which employs scintillation counters. A new high temperature X-ray powder diffraction technique in which a thermocouple acts as specimen support and heater will be shown by the Building Research Station.

Infra-red spectroscopy will form an important part of the Sir Howard Grubb, Parsons exhibit. They will show a simplified double-beam grating infra-red spectrometer, a fixed wavelength infra-red gas analyser using a diffraction grating, infra-red gas analysers for plant control—both direct deflexion and null-balance models, and an infra-red gas analyser with pneumatic null balance. A number of components for infra-red gas analysis will be shown by the Infra Red Development Company. Optica United Kingdom will show what was the first recording **ultra-violet spectrophotometer** in Britain, their double-beam ratio-recording grating spectrophotometer.

Polarography is well covered by Mervyn Instruments, who will show their square wave polarograph, Mark III and also a polarographic electrode to a Water Pollution Research Laboratory design, which enables a continuously flowing liquid to be monitored. Cambridge Instrument will show a simple and inexpensive general purpose polarograph, and Ericsson Telephones their type 143A automatic polarimeter. AERE, Harwell, will show a differential cathode-ray polarograph.

Equipment for **chromatography** and electrophoresis will form the basis of the Baird & Tatlock display. W. G. Pye will show their Argon chromatograph, which is said to have a limit of detection of 1 part component in 2 × 10^5 of argon. A **potentiometer recorder** suitable for use with gas chromatographs will be shown by Sunvic Controls.

The Chemical Inspectorate of the Ministry of Supply will show a method of **automatic titration** giving continuous recording of visual change and yielding a chart of continuous pH record. Doran Instrument will also show a new device for automatic titration. Evans Electroselenium will show a titrator, together with a fluorimeter for measuring the fluorescence of liquids and an adjustable gloss head for measuring gloss at angles other than the normal 45°.

A **sulphur dioxide recorder** for the Central Electricity Research Laboratories will be shown by Mervyn Instruments. This will analyse sulphur dioxide in the atmosphere down to 0·01 parts per million.

Monitoring washing processes in transistor production and electroplating is the task of an **elution bridge** by Griffin & George. This is a Wheatstone bridge having conductivity cells in two arms, one of the cells being in the influent line to an elution vessel from which effluent passes through the other cell. A **continuous conductivity analyser** will form part of the Swedish LKB stand; a Wheatstone bridge device, it has a measuring range of 5 × 10^{-6} to 4 mhos and an accuracy of ± 0·25%.

The Chemical Defence Research

DON'T MISS

★ **Conditional probability computer**
National Physical Laboratory (DSIR)

★ **Superconducting computer memory element**
RRE (Ministry of Supply)

★ **Helisyn position control system** *British Thomson-Houston*

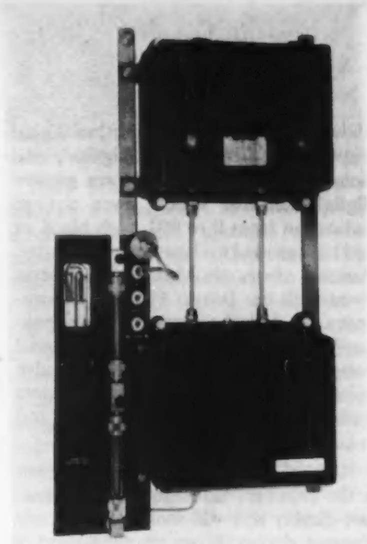
★ **Syncrotel angular position control transmission element** *Kelvin & Hughes*

Establishment will show an **automatic toxic gas alarm** based upon photoelectric recognition of the colour of a filter paper. An **electrostatic dust monitor,** by BTH, measures dust concentration in a gas stream and has application to power stations. The Statigun **static charge detector** by Baldwin Instrument measures the potential gradients in air over the range 0–300 kV/ft.

Baldwin are possibly best known for their range of 'Atomat' **nucleonic thickness gauges.** Their fast responding model for the automatic thickness control of high speed material, such as metal foil, has a response down to 0·1 sec or, with a special cable, 0·04 sec. A phototransistor-actuated limit controller which will operate heavy duty contacts from a few microamperes, will also be shown. A beta thickness gauge for the continuous measurement of thickness of all sheet or strip material, will also be shown by Isotope Developments. Ekco Electronics will show a new *Bremsstrahlung* gauge, utilizing a strontium-90 source, which covers the continuous thickness measurement of brass, steel, copper, etc up to 0·4 in. thick. A density gauge which employs gamma radiation and a geiger counter, will be shown by Cawkell Research Electronics. British Physical Laboratories will show a resonant circuit tin-plate thickness meter having a f.s.d. of 45 microns.

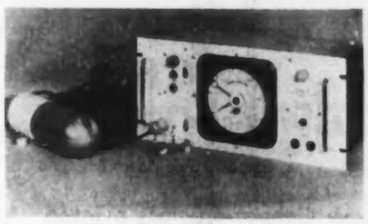
Many firms, including Baldwin, Isotope Developments and Ekco Electronics, will show **nucleonic instruments** and ancillaries. The UKAEA will, of course, be there in force, and among other nucleonic firms showing will be Nuclear Enterprises (GB), Panax Equipment, EMI (hand and clothing monitor) and Burndept, who will also show a number of automatic instruments. A largely-transistorized **pulse height analyser** will be exhibited by Sunvic Controls. Fleming Radio will show an **effluent monitor** for lakes and rivers contaminated with radioactive material, and an automatic **air pollution monitor** for checking radioactivity.

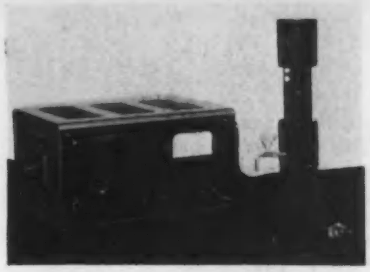
It is impossible to cover all the general instrumentation to be shown; we can hope only to draw attention to but a few devices. For example, Techne (Cambridge) will show an absolute **viscometer** which can be used on non-Newtonian liquids, and a **gelation timer** for assessing the time taken for a liquid to gel. Wayne Kerr will show devices based on their **transformer ratio-arm bridge,** including a low impedance comparator for studying the salinity of sea-water, and a high impedance comparator for measuring dissolved water in oil. A **furnace flame indicator,** for the CEGB, which gives remote indication of combustion conditions, will be among the exhibits of H. Tinsley & Co.



Null balance magnetic oxygen analyser (*The Distillers Co Ltd*)

Gamma monitor having flexible alarm facilities (*Labgear Ltd*)





The ETL-NPL automatic polarimeter (*Ericsson Telephones Ltd*)

Self-standardizing 'Atomat' beta-ray thickness gauge with remote control unit (*Baldwin Instrument Co Ltd*)

Computation and data handling

One of the most interesting demonstrations at the Show will be the imitation of learning by the NPL's **conditional probability computer.** This records the occurrence of five events, counts how often each occurs and how often each possible conjunction of events occurs. From this it calculates, when any set of events occurs, the conditional probability of the other events. A model of the NPL's Ace digital computer will also be on view.

Elliott Brothers will show **digital computing equipment** including transistor circuits, a transistorized switching element, a transistorized nickel delay line register, and their paper tape reader designed by Cambridge University, which has a reading speed up to 100 characters/sec yet can stop on a single character. Elliotts will also show ancillary equipment for use with their G-PAC **analogue computer.** Their Miniac desk top computer will be shown.

A Space analogue computer with 20 drift-corrected d.c. amplifiers, and several diode function generators and servo multipliers will be demonstrated in use by Solartron. They will show several new units including a shaft-position servo unit which can be supplied as a multiplier, resolver or tapped potentiometer, a Hall effect multiplier and a fast parallel binary adder.

The Fairey multi-purpose analogue computer will also be on show. Fairey suggest its use for control system design and as a **simulator** of plant components.

Several organizations will show **analogue-digital convertors** including: Racal, whose device will be demonstrated measuring voltage, resistance and capacitance and giving digital indication; Mullard, whose instrument will convert an analogue input voltage into a binary output of 10 'bits' at high speed; CNS Instruments, whose mechanical convertor comprises a shaft input which is caused to operate microswitches and, thence, an electric typewriter; Dobbie McInnes, an instrument of three-decade Kelvin Varley potentiometer type, which will convert analogue voltages to decimal digits with sign resolution of 1 part in 999.

GEC Research will show a prototype **induction digitizer** which gives a numerical representation of the position of a shaft or slide in the form of electrical signals, without using slip-rings or photocells. A precision slide-wire potentiometer by Kelvin Hughes will convert angular rotation to resistance or voltage.

An analogue-digital convertor is employed in one of two forms of **trace analysis equipment,** which is also by Dobbie McInnes. This is a semi-automatic system for the reduction of analogue data recorded on paper or film. Cambridge Instrument will exhibit an **automatic chart analyser** for the

automatic sampling of recorder charts. This employs a photoelectric detector and a servo system, the whole giving a digital output. An X-Y **plotter** to be shown by Ekco Electronics, gives a record of two variables (d.c.) on a 10 in. by 7½ in. plotting area.

A **superconducting computer-memory element** by the Royal Radar Establishment should arouse interest. A superconducting surface carries a persistent current inductively 'set-in' and which is, subsequently, inductively 'read'. Setting and reading times are better than 10^{-7} sec. A new version (MD4) of the Pegasus **magnetic drum** will be shown by Ferranti; this 6 in. by 10 in. diameter drum has a capacity of 9216 42-bit words. EMI will show a range of magnetic drum stores with 8000 or 16,000-word capacities, together with magnetic heads for 'out-of-contact' operation on drum and tape stores. **Memory cores** planes and complete stores in 'Ferramic S.4' will be exhibited by Plessey, whilst Telcon will show a matrix of 'Microstrip' cores. Mullard Equipment intend showing their variable **magnetostrictive delay lines.**

A **magnetic disk recorder** by Smiths Industrial Instruments employs a novel technique. A permanent magnet disk is rotated and a moving-coil stylus travels radially across the disk. A third of the rotation of the disk is erased, and the remaining two-thirds provides a graph of speed against time.

The Midas system of **magnetic tape data recording and processing** will dominate Royston Instruments' stand. This is an integrated and flexible multichannel system for the accurate recording and subsequent re-presentation of data for assessment and analysis, and for control, storage, monitoring and indexing. Solartron have produced a recorder-reproducer for data handling and which is available as a 7- or 14-channel system. EMI will also exhibit an instrumentation tape desk; four or six tape speeds within the 0·5 to 120 in./sec range are available and up to 24 channels on 1 in. tape can be provided. Mullard will show a transistorized **tape telewriter and sender** and Ferranti a transistorized **tape reader** which can read punched paper photoelectrically at speeds up to 1000 characters/sec. G. V. Planer will be among firms showing **magnetic recording tape.**

There is a noticeable trend towards **digitally-indicating instruments** and many such will be on show. The National Gas Turbine Establishment will show a **digitized high-speed galvanometer** which employs optical projection of a digital scale, in conjunction with photoelectric 'reading' equipment, to give a good response time. Pullin will show an 'in-line' rear projection digital display unit—the 'Aldis Digilite', and Solartron a transistorized **three window digital indicator** which gives voltage indication from 0 to 999, with black or red background to show voltage polarity. Among others showing digital instruments will be: British Physical Laboratories—a digital voltmeter; Metropolitan-Vickers—a peak-reading digital voltmeter; Burndept—a digital valve voltmeter; Ferranti—digital voltmeters and ohmmeters; Ericsson; Racal; and J. Langham Thompson.

Also of information display interest is the Distillers Co **panoramic temperature display unit**—24 thermocouples are scanned during 1½ sec to display on a cathode ray tube, the temperature distribution in a chemical reactor. BTH will show **electroluminescence** for information display, and the UKAEA will show **atomic light sources.** English Electric Valve will exhibit their new E702 **daylight viewing, storage, cathode-ray tube.**

DON'T MISS

★ **Hyper-pure silicon for semiconductors** *Standard Telephones & Cables*

★ **Copper-on-glass printed circuits** *G. V. Planer*

★ **4π gas flow counter** *Labgear*

★ **Power transistor—8A, 10 W peak** *GEC*

Position, torque, speed and allied equipment

The position of a shaft within a bush is useful in journal-bearing investigations, and the Mechanical Engineering Research Laboratory have developed a **shaft position indicator,** employing systems of inductance transducers. Racal will demonstrate shaft positioning by digital means, using an add-subtract counter.

The NPL will exhibit **displacement measurement** using gratings and electronic counters, and the Royal Radar Establishment a method of measuring very small mechanical displacements using a capacitance technique and a h.f. transformer bridge. Wayne Kerr's electronic micrometer is also a capacitance-bridge device for measuring distance between 100 μin. and 45,000 μin. to an accuracy of 1%, using a non-contacting probe. Apart from displacement measurement, the NPL will also exhibit an **extensometer** for creep strain measurements. This uses a linear differential transformer in a mutual inductance bridge and covers extensions of 0·00002 in. up to 0·20 in. over test periods possibly exceeding 10,000 hours.

The Helisyn position-control system for precise **linear mechanical positioning** in response to a numerical input will be shown by BTH. This comprises a short cylindrical part which can be moved along—but does not contact—a longer cylinder. Both parts incorporate conductive paths in the form of interlaced helices so that electrical excitation of one element induces a misalignment signal in the other element.

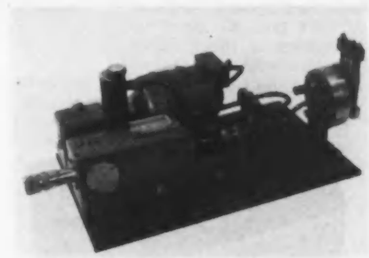
The 'Syncrotel' to be shown by Kelvin Hughes is an **angular position transmitting** element of the synchro family, whose stator is of the conventional three-phase type but, instead of a rotor, a fixed single-phase winding on a bobbin is used. 'Syncrotels' may be used in back-to-back pairs, but are usually employed in servo systems with an ordinary synchro receiver. The Inspectorate of Electrical and Mechanical Equipment will exhibit a 72-position (5° steps) **dividing head** for testing synchros for angular accuracy.

An automatic weighbeam for **measuring pressure and torque** will be demonstrated by the Mechanical Engineering Research Laboratory. Pressure (0 to 500 lb/in²) is applied to a piston to displace the weighbeam, a servo system driving a weight along the beam to bring it back to the horizontal.

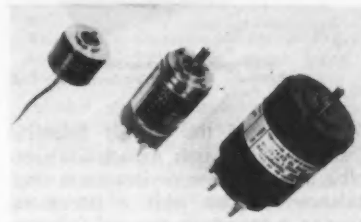
Various mechanical devices will be shown by Elliott Brothers. A **ball bearing torque tester** measures frictional torque under load, the inner race being driven whilst the outer race's attempt to follow is restricted by a spring. Movement of the latter is detected, and the resulting signal is amplified and recorded. Elliotts will also show a **mechanical phase selection coupling** which permits two shafts to engage only when in the correct relative angular position, a **ball type slide assembly** comprising a pair of V-grooves between which run steel balls, and a **potters wheel variable speed gear integrating mechanism.** The latter provides an infinitely variable gear and can be used for integrating analogue functions. Elliotts will also exhibit an **a.c. gyroscope** for 333 or 400 c/s supplies and speeds of 19,000 and 23,000 r.p.m.

An interesting mechanical positioning device is incorporated in the Swedish LKB ultra microtome, which provides sections for electron microscopy. During a cutting cycle, the specimen, which is mounted on an expansion rod, moves vertically and passes the knife twice. The cut is made on the downward stroke.

Voltmeter giving digital presentation
(*Ferranti Ltd*)



One of a range of variable-capacity pumps for the accurate metering of fluids
(*The Distillers Co Ltd*)



A servomotor and synchros representative of the Pullin-Kearfott range
(*R. B. Pullin & Co Ltd*)

Electronic micrometer for high accuracy distance measurement
(*The Wayne Kerr Laboratories Ltd*)

To prevent the knife contacting the specimen during the upward stroke, it is automatically retracted, 20 to 30 microns, by electromagnetic means.

Airmec will show their N266 **proximity detector**, a capacity switch which operates a relay system when any substance is brought within a predetermined distance from the sensing probe. Burndept will exhibit a proximity switch and a range of probes for control of temperature, moisture level and liquid level.

A **yarn speed indicator** to be shown by Smiths Industrial Instruments is calibrated 100 to 800 ft/min and has an accuracy of $\pm 1\frac{1}{2}$ f.s.d. Operating on a magnetic principle it is intended for the speed measurement of wool, cotton, or man-made fibres on revolving cylinder knitting machines.

Synchros and servomotors will be shown by R. B. Pullin. These include sizes 11 and 18 synchros in the Pullin-Kearfott range, a 7-terminal size 11 control resolver (R982-21B BuOrd 11R 13N4), and size 10 servomotors for germanium and silicon transistor-amplifier operation. Other Pullin exhibits include size 10 motor generators, transistor and magnetic amplifiers, d.c. motors, instrument motors and tachometers. Ketay will show an International Standard size 11CX4a synchro and an a.c. tachometer generator (type 105T2H) with a performance of 1/1000 V/r.p.m. to within $\pm 0{\cdot}2\%$, and linearity of $\pm 0{\cdot}12\%$ from 4000 r.p.m. clockwise to 4000 r.p.m. anticlockwise. Electro-Methods will have new cylindrical low-inertia motors including a small version for instrument servo systems; a range of gearboxes is available. Similar to their small motor is a low-friction tacho-generator. A range of synchros and servomotors will also be shown by Muirhead including 60 c/s servomotors and motor tachometers in size 15 and 18 frames; miniature size 08 synchros; size 08 and 10 servomotors; size 11 Linvars; and a size 11 gearhead for instrument servomechanisms. Elliotts will exhibit a range of servo components.

DON'T MISS

★ **Peltier effect semi-conductors** *Plessey Co*

★ **Fatigue testing with ultrasonics** *Mullard Research Laboratories*

★ **Accurate hydraulic amplifier with integrating features** *Elliott Bros*

★ **X-ray microanalyser** *Metropolitan Vickers*

The Muirhead **transfer function analyser** for frequency response testing automatic control systems will be demonstrated. This comprises a l.f. decade oscillator for exciting the system, a l.f. phasemeter for measuring phase and amplitude between two signals, and a tunable filter. The Solartron t.f.a. reference resolver provides digital presentation of polar coordinates when using the Solartron t.f.a. Transfer function analysis in the frequency range ½ cycle/hour to 100 c/s is the duty of the Solartron process response analyser, which has been designed for the study of process control systems.

Rotational shaft speed measurement up to a maximum beyond the rotational velocity of any practical machine, is possible with Dawe Instruments' transistor frequency meter and photoelectric pick-up, which will be exhibited. Furzehill Laboratories will demonstrate a three-phase variable frequency supply originally developed for **testing speedometers** and similar devices requiring accurately known shaft speeds. This drives a synchronous motor-gearbox giving shaft speeds from a few hundred to several thousand r.p.m. to an accuracy within $\pm 0{\cdot}25\%$.

Pressure and flow

The Low Temperature Research Station (DSIR) will demonstrate a simple electromagnetic valve for the **control of gas flow.** As demonstrated, the valve will be controlled photo-electrically by the height of a column of liquid in a manometer.

Kelvin Hughes will show a **force-balance system** for pressure measurement which can be adapted to measure absolute or differential pressures over the range 1 to 100 lb/in^2. The Ketay **pressure ratio computer** to be shown was originally developed for measuring and indicating angle of incidence in high speed aircraft, but has obvious application to other fields where the ratio of two pressures is required, e.g. pressure-ratio controllers, or in differential gas flow.

The accurate metering of small quantities of fluids where constant pre-set flows are necessary is the duty of a range of **metering pumps** to be shown by the Distillers Co. 'Micro-pumps' are available in nine sizes of infinitely variable capacity from 0–7 to 0–1500 ml/h. 'M' pumps are in 10 sizes from 0–750 ml/h to 0–37·3 l/h and are available for proportional signal, or with hydraulically operated diaphragm heads.

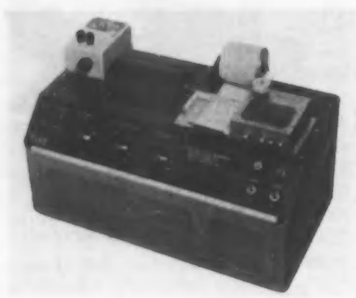
Designed for use with positive displacement flowmeters is the Ericsson industrial batch counter, type 165A. This facilitates the dispensing of accurate quantities of liquid.

Edwards High Vacuum will, of course, show a large range of vacuum equipment and accesssories.

As manufacturers of infra-red gas analysers, Infra-Red Developments have produced many components for use with gas sampling equipment. Among such equipment on show will be variable and preset throttling valves, flow controllers, pressure relief valves and absolute pressure regulators.

Pneumatics applied to instruments will

The type W.M.7 general purpose oscilloscope. Note plug-in units (*EMI Electronics Ltd*)



High speed level recorder (*Dawe Instruments Ltd*)

form part of the British Scientific Instrument Research Association's exhibit. Among these devices are a ring-balance recorder with a pneumatic bearing, a pneumatic cam and follower, large range non-contact pneumatic gauging, a pneumatic level gauge, and a pneumatically-guided depth-indicating float.

Some transducers

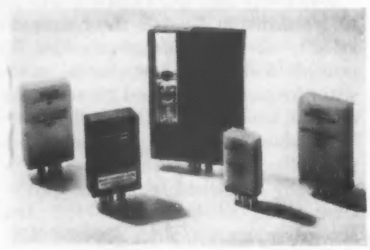
An interesting application of **resistance strain gauges** is a device by the Road Research Laboratory, for recording axle loads of fast moving traffic. A 6 ft by 9 ft table is set in the road with a gauge in each of the four legs of the table. The gauges form part of a bridge circuit feeding a galvanometer. The load associated with each axle causes the galvanometer to sweep a light across a row of photocells each actuating a counter. The number of counts is a measure of axle loading.

G. V. Planer will show a number of transducers including indium antimonide **magneto-sensitive resistor and Hall effect elements. Variable reluctance transducers** for displacement or proximity measurement, for surface study, in pick-offs and pressure gauges will be shown, as will **piezoelectric ceramics.**

Various transducers will be shown by J. Langham Thompson. Their pressure types have an overall accuracy within $\pm 1\%$ at full output. Models BP1 and

Probe of an indium antimonide displacement gauge (*G. V. Planer Ltd*)

Pressure transducer of resistance strain gauge bridge construction (*J. Langham Thompson Ltd*)



Transistorized 'packaged' stages (*Venner Electronics Ltd*)

BP2 are of **resistance and differential strain gauge bridge construction** respectively, while BP3 will measure both steady and rapidly fluctuating pressures. This company will also show unbonded strain gauge dynamometers and load cells, differential inductance transducers and differential displacement transducers.

Noise, vibration and ultrasonics

Dawe Instruments will be prominent among those showing **ultrasonic cleaning equipment**, their exhibits including a 2 kW generator for up to 10 gallons capacity, a small 250 W generator, and a 2 kW surgical instrument cleaner. Their **stroboscopes** will include a high intensity, four-lamp model—up to 6000 flashes/min—and a battery-operated transistor model for speed measurement from 600 to 15,000 r.p.m. A range of **noise meters** will also be shown. A **vibration meter** by Wayne Kerr measures distance and vibration from 50 μ in. to 0·5 in. in the band 1 c/s to 10 kc/s. Nagard will show a phototransistor displacement pick-up for vibration measurements.

Ultrasonic testing equipment will be shown by Ultrasonoscope including their general purpose flaw detector (500 kc/s – 10 Mc/s) and a range of search probes. Kelvin Hughes will show a new range of transducers for immersion or contact tests. An instrument which produces a pulse signal in a material (e.g. a road surface) by means of a hammer blow will be shown by Cawkell Research & Electronics.

Components and materials

Electronic valves and tubes and semiconductors will be exhibited by such firms as Mullard, EMI, English Electric Valve, GEC, BTH (silicon transistor developments) Megatron (selenium photocells), Electronic Tubes (a c.r.t. of high deflexion-sensitivity), Ferranti, Plessey (semiconductors), several Ministry of Supply Establishments, Standard Telephones and Cables, and Siemens Edison Swan.

Turning to materials and components in general, such exhibits will include ceramic-metal seals by Ferranti; heavy alloy for screening gamma radiation by GEC; copper-on-glass printed circuits, ferrites and metal-ceramic bonds by

DON'T MISS

★ **Pulse height analyser—large transistorized** *Sunvic Controls*

★ **Novel applications of pneumatics** *British Scientific Instrument Research Association*

★ **Transformer ratio-arm bridge techniques** *Wayne Kerr Labs*

★ **Panoramic temperature display unit** *Distillers Co*

G. V. Planer; components in tantalum, niobium, tungsten, molybdenum and zirconium by Murex; 'Spectrosil' high temperature material by the Thermal Syndicate; transistorized packaged stages by Venner Electronics; magnetic alloys and frozen-mercury castings by Telegraph Construction and Maintenance; noble metal resistance wires, magnetic alloys, tungsten base metals, platinum metals, and pressure bursting disks by Johnson Matthey; and optical and other glasses by Chance Pilkington.

It is impracticable when previewing an exhibition of this size and importance for us to do more than hint at the great diversity of products on show. To many, the Physical Society Exhibition is one of the great events of the instrumentation year, and this importance is reflected in the yearly catalogue of the Show, the Physical Society's *Handbook of Scientific Instruments and Apparatus*. In our opinion, the *Handbook* is much more than a mere catalogue; it is a reference work of calibre.

TRANSFER FUNCTION ANALYSERS

MUIRHEAD & CO

The Muirhead analyser comprises three instruments available separately, a low frequency phasemeter at £575, a tunable filter at £85 and a low frequency oscillator at £325 (this is not required if the customer already possesses a suitable oscillator)

The combined equipment has a frequency range of 0·5 to 10,000 c/s and can deal with phase differences from zero to 360° and amplitude differences up to 70 dB.

Low frequency phasemeter (D-729-B) and tunable filter (D-925-A)

Frequency range 0·5—10,000 c/s

Form of indication Instrument indicates phase angle over all four quadrants on a 4 in. panel meter having four scales 0°–90°, 180°–90°, 180°–270° and 360°–270°. The meter also carries two voltage scales 0–6 and 0–20 V or mV. The calibrated input attenuators enable voltage level difference up to 70 dB between the two inputs to be measured.
The operation of the phasemeter depends on the fact that the vector sum of two alternating voltages is a function of their individual amplitudes and the phase angle between them.

Accuracy of indication Phase angle: ±1° above 1 c/s, decreasing to ±3° at 0·5 c/s. Level difference: ±2% (0·2 dB) above 1 c/s decreasing to ±5% (0·5 dB) at 0·5 c/s.

Harmonic rejection $2f$ or $f/2$: better than 26 dB. $3f$ or $f/3$: better than 30 dB. Max. rejection of higher harmonics is 36 dB.

Reference It is not necessary to use the oscillator voltage as a reference: direct readings of phase angle and relative amplitude between any two points of a system are possible. Thus the transfer function of an individual component or a group of components in a system can be determined.

Remarks and special features The presence of the tunable filter enables the signal frequency to be measured to an accuracy ±5%. Actual voltages (as distinct from relative amplitude) can also be measured.

2-phase low frequency decade oscillator (D-880-A)

Frequency range 0·01—11,200 c/s (continuously variable above 0·1 c/s)

Accuracy ±2% above 5 c/s decreasing to ±1% at 0·1 c/s; ±2% from 0·01 c/s to 0·1 c/s

Output 0°–10 V into 600 ohms resistive; 90°–10 V into 10 k ohm resistive. Constancy of output level is ±1 dB, over entire frequency range; d.c. content is better than 1% of the peak-to-peak output voltage.

Harmonic distortion 0° output—0·5%; 90° output—1·5%

Remarks and special features A power output of 10 volts into 600 ohms (160 milliwatts) is available via a 62 dB continuously variable attenuator over the entire frequency range: this is known as the 0° phase output. Another output, known as the 90° phase output (which lags the 0° phase output) provides 10 volts into 10 k ohm. This output is variable down to zero.

Tick No 149

SHORT BROTHERS & HARLAND

The voltmeter and oscillator are fitted in a single cabinet with a separate cabinet for the power supply unit. The two cabinets are each 21 in. wide, 13 in. high and 18 in. deep. The cost is £998 ex-works.

Oscillator section

Frequency range 0·01—109·9 c/s

Accuracy ±1·5%

Output Direct—20 V peak at 15 mA max. amplitude controlled to ±1% by built-in control circuit. Attenuated—variable from 0—20 V by 10-turn potentiometer. Attenuator ouput impedance is 1000 ohm max. The d.c. component of output is less than 100 μV on direct output and correspondingly less on attenuator output. A d.c. component of less than 0·0005% can be readily maintained by correct balance of the drift corrected amplifiers.

Harmonic distortion Less than 0·5%

Additional outputs 1. Ramp voltage, positive or negative, variable from 0·1 to 100 V/sec. Max. 20 V at 15 mA. 2. Step voltage, positive or negative, 20 V at 5 mA max.

Remarks and special features The sine wave commences from zero and the network is so arranged that on switching off there is an exponential decay of the sine or cosine output. This decay enables the oscillator to test delicate servo systems where abrupt discontinuities in the oscillation might otherwise cause great damage.

Phase sensitive voltmeter section

Frequency range 0·01—109·9 c/s (up to 1·5 kc/s with external oscillator)

Form of indication Meter—0 to 150 V in 8 ranges on centre zero. Lowest range 50 mV full scale.
Phase and quadrature components of the system output are measured by forming the integral of the product of the signal and reference voltages over one cycle. In this way the effect of harmonics or a d.c. component in the system output is reduced to negligible proportions.
The meter pointer comes to rest when the integration is complete; the stored integral voltage is then displayed at a steady deflexion.

Accuracy of indication Within 2% of full scale.

Harmonic rejection Better than 40 dB on all ranges. d.c. is completely rejected provided that the sum of signal and d.c. voltages does not exceed the full scale reading.

Reference Direct internal connexion of required sine and minus cosine from the oscillator section.

Tick No 150

SOLARTRON ELECTRONIC GROUP

The basic unit is the transfer function analyser, consisting of a low-frequency decade oscillator (OS 103·2) and a resolved components indicator (VP 253·2), housed in separate cabinets. The cost of the combined unit is £1300.

Oscillator section (OS 103 2)

Frequency range 0·01—11,100 c/s

Accuracy ±1·5%

Output 4-phase constant level outputs at 0, 90, 180 and 270°. 10 V/phase (built in attenuator on two phases). Amplitude stability is 5%

Harmonic distortion 1%

Additional outputs A single phase squarewave output is provided

Resolved components indicator (VP 253·2)

Frequency range 0·1—1000 c/s

Form of indication Two 6 in. thermocouple wattmeters, each giving a direct reading in cartesian co-ordinates

Accuracy of indication ±3% f.s.d.

Harmonic rejection Better than 40 dB

Reference 10 V r.m.s. for each phase

Remarks and special features Signal sensitivity is 50 mV to 150 V and signal input impedance is 10 megohm.

Another piece of equipment, the process response analyser (JY 743), is similarly made up from a low frequency decade oscillator (JO 744) and a resolved component indicator (JD 745), but is designed for frequencies from 1 in 3 hrs to 100 in 1 sec. The price is £2950.

Oscillator section (JO 744)

Frequency range 0·0001—100 c/s

Accuracy ±1·5%

Output Sinewave voltage: 4 phase, 100 V peak/phase
Sinewave current: 0° and 180° – 5 mA peak (100 V into 20 kohms). 90° and 270° – 2 mA peak (100 V into 50 kohms).
Amplitude stability is better than 1% over entire frequency range.

Harmonic distortion Less than 0·5% total

Additional outputs Square wave and triangular: 0 – 20 V/phase

Remarks and special features Provision for remote digital indication of frequency and amplitude, also remote programming from a computer or simulator

Resolved component indicator (JD 745)

Frequency range 0·0001—100 c/s

Form of indication (a) Meters, effective scale length 11 in.
(b) Simultaneous analogue voltage output

Accuracy of indication ±3% of full scale

Harmonic rejection Better than 40 dB

Reference 4 phase reference input is required (obtainable from oscillator JO 744). The signal input sensitivity is 3 mV – 300 V (full scale) in 11 half-decade ranges. The signal input impedance is 1 megohm or 10 megohms with 20 dB attenuator. Noise integration period is, 1 c/s and below—one cycle, variable—above 1 c/s.

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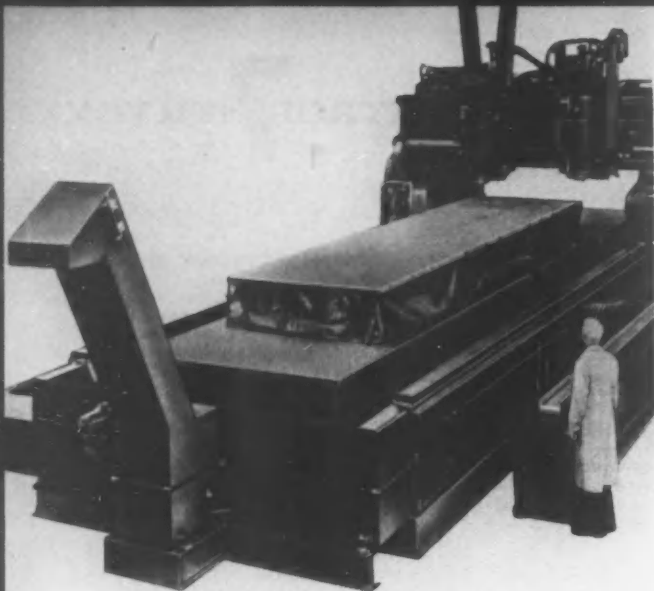


PART

2

An EMI engineer continues the examination of his company's system of numerical control by looking at the servos and extended analogue unit

by **A. T. MACDONALD, B.Sc.**
Industrial Applications Division, EMI Electronics Ltd

Programmed machining

2.3 Programming

In normal production methods the production planning department will supply information concerning the production process such as material to be used, size of blank, the cutter diameter and type, what fixtures will be required, etc. In numerically controlled production one new feature is introduced, that of programming, which is the preparation of dimensional information from a drawing in a form suitable for feeding into the machine. The work involved in programming is such that it can be done easily by any individual having a knowledge of elementary trigonometry.

2.3.1 General features

The description of programming will refer to a two-dimensional system. The principles can easily be extended to cover any number of dimensions.

The programmer receives the engineering drawing of the piece part; from this the co-ordinates of the points on the profile are worked out. The numbers defining these points are given to the machine in a coded form which it interprets. The code is formed by a pattern of holes on the paper tape, which is prepared automatically when the data is typed on a teleprinter with a modified keyboard. The keyboard is designed for easy working by both skilled and unskilled operators.

If the cutter size falls within the range of the cutter compensation unit, then the programme planner can punch the information for points on the profile of the work piece directly onto the tape. If the cutter diameter size falls outside the range of the compensation unit, the programme planner chooses a nominal diameter of the cutter and calculates points on the path of its centre.

The first points to be worked out are those where sudden changes in direction or curvatuie occur, e.g. where two straight lines meet, or where a straight line is tangential to a curved path. These points are called the change points and this initial procedure is common to all computer-controlled machine tool systems at the present time. In the system that is being described further points are calculated between the change points. The machine control traces a smooth parabola through each set of three points. The end points are termed major points, the intermediate ones minor points. A sudden change of direction can only take place at a major point, therefore the change points on the profile must be associated with a major point of a parabola. The number of points between the change points will depend on the shape of the profile. If it is a straight line then a minimum of three points are required. Additional points may be added so

Fig. 7 The range of an analogue measuring system can be increased by adding a repeating fine range to the basic short range. This device here is of linear form and is called the extended analogue

that the distance between them does not exceed a certain value. If it is a circular arc then the points must be close enough so that the error due to the parabolic interpolation is within tolerance. The formula for determining the maximum point spacing is given by

$$\sin\frac{\theta}{2} = \left[\frac{E}{R}\left(2 - \frac{E}{R}\right)\right]^{\frac{1}{2}}$$

where θ = angle between adjacent data points
E = the tolerance zone
R = radius of the arc.

The above formula is for three-point intersection, and an undesirable cusp may be formed if an external contour is being machined. In this case the parabolas can be fitted to the circular arc in such a manner that, at the points of intersection between the parabola and the circle, the parabola is tangential. The slope at the end of one parabola is equal to the slope at the start of the next. No sudden changes of gradient will occur and the surface will be free of cusp marks. The formula for tangent matching is given by

$$\cos\theta = 1 + \frac{E}{R} - \left[\frac{E}{R}\left(\frac{E}{R} + 2\right)\right]^{\frac{1}{2}}$$

In many programmes the trigonometry involved is

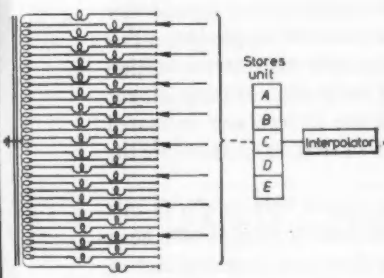


Fig. 8a A simplified circuit of the extended analogue unit

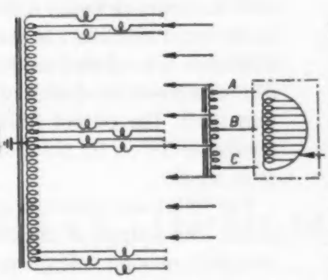


Fig. 8b The extended analogue unit showing stores A, B and C set up to points between switch wipers

repetitive, and to facilitate rapid programming a series of standard forms have been introduced. The experience over a large number of differing piece parts has been that most time is spent on calculating the ordinates of the change points. The tape also carries some extra information, such as stopping and head lowering instructions, while many other instructions may be added, e.g. cutter speed and coolant on-off commands. The complete cutting operation covering such details as feed rates, etc, should be decided when the programme is prepared. The control tapes can easily be spliced together with adhesive tape, insertions and modifications are made quickly and economically. A valuable feature is that with a little practice, the programmer or operator can read the coded information on the tape.

2.4 Servomechanisms

The error between the required table position and actual table position is kept to a low value by means of a servo system. Both electrical and hydraulic servos are in use.

At the lower powers, a split-field d.c. servomotor developing 1/7 h.p. is used, and this has been found adequate to drive a No 3 size vertical milling machine at speeds up to 20 in/min. The servo system is stabilized by transient velocity-feedback, and by such means a low velocity lag is obtained, without recourse to deriving the demanded velocity and feeding it forward. The stiffness of the system is such that half motor torque is produced for a static error of 0·0001 in. The servo amplifier is one of the few units that use thermionic valves. The presence of lost motion between the servomotor and the leadscrew has a degrading effect on the servo performance. Thus great care has been taken in the mechanical design of the drive to ensure that lost motion is kept to a minimum.

To cover the power range up to 1 h.p. a Ward Leonard control is being developed. The generator has a laminated field with split-field windings and the field will be driven from hard valves to reduce the field time-constant. The Ward Leonard system is essentially a speed control, so that when used in a positioning system the demand velocity would have to be derived to prevent large velocity errors. However, by using velocity-feedback through non-minimum-phase networks, a low velocity lag system can be obtained, which is controlled by the position demand signal only.

2.5 Hydraulic servos

For large powers hydraulic servos are used. The simple piston and cylinder can give good results if the slide stiction is low, but owing to oil compressibility the performance deteriorates if the slide stiction is significant. Hydraulic motors driving leadscrews have been found to be satisfactory. The motors are controlled from two-stage electrohydraulic valves. Such a system has been used to power a skin milling machine with a table motion of 31ft 6 in. and a head motion of 8 ft at controlled speeds of up to 150 in/min.

2.6 Machine design details

The overall performance is greatly affected by design of the machine tool, and much development still lies ahead in this field. The cutting head must have adequate bearing stiffness to prevent deflexion under the cutting loads and to prevent tool chatter. Up to the present time the slides have been of orthodox construction, but work is in hand to reduce slide friction by the use of recirculating linear ball bearings.

2.7 Reliability

It is obviously important that a high standard of reliability should be obtained in the equipment, and a great deal of attention has been paid to this aspect. From the description of the various units it will be apparent that they are mainly constructed of toroidal transformers, relays and rotary-stud switches. The transformer cores are fitted in cases before being wound, and after winding the whole transformer is dipped in a plastic bath. The finished transformer is in fact nearly indestructible. The relays are of the sealed type to ensure no dust interferes

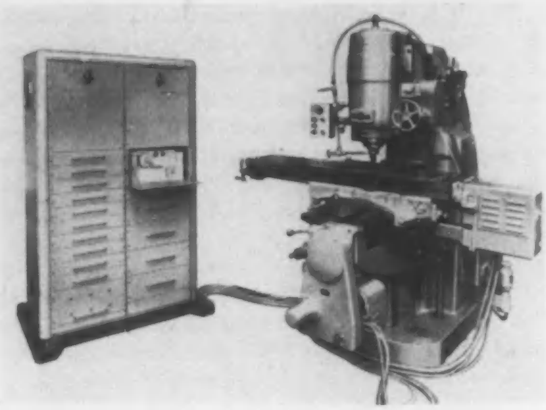


Fig. 9 The first machines to be fitted with a contouring system were knee-type vertical millers, such as this Cincinnati 3. It is controlled on the *X* and *Y* motions only

with the contacts, and after an initial testing period the relays have proved to be very reliable.

The rotary stud switches are of a unique design and are the result of a considerable amount of development work. The studs are of silver alloy and the wipers of gold alloy. The shape of the wipers has been chosen to give low contact resistance, and the stud switches require only a small amount of regular maintenance.

A safety unit is incorporated in the machine console. This unit continuously monitors the position errors in the various servo amplifiers. If any error exceeds a preset amount the safety unit operates and stops the machine motions.

2.8 Production time

The use of numerical control is justified by the saving in production costs due to the reduced production time. For a single piece part the overall time, including programming, is usually about one-half that required by normal production methods. For a larger number of parts the proportion of the programming time becomes less; the production time then varies from one-half to one-fifth of that required by normal methods, depending on the number of parts produced.

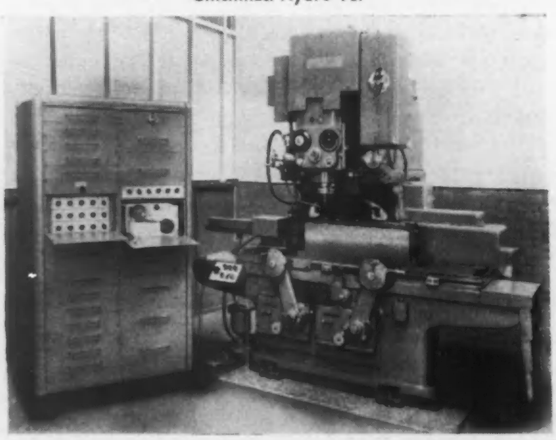
2.9 Extended analogue

In the system as described, one analogue range was used to cover the full length of the machine motion. It is a common practice in analogue measuring systems to have a repeating fine range, and by this means the accuracy of a short range can be extended to cover a much larger scale. Most analogue systems of this nature are of cyclic form, such as a sine wave, but a system has been devised for a linear device, and it is termed the extended analogue. With this system the computation accuracy of a 10 in. range can be obtained on much longer ranges without additional electrical errors. The only unit to be modified is the position analogue unit. However, before describing the modified position analogue unit, an explanation of the principle will be given with reference to Fig. 7. A rotary potentiometer has two wipers A and B. These wipers can be locked to the input shaft at any position round the potentiometer. As will be seen from the diagram, if S1 is switched to B, then the servomotor will drive the shaft round until wiper B is opposite the earth point. Wiper A can now be repositioned to say, position 3, and the switch S1 returned to wiper A. The shaft will again be driven round until A is opposite the earth point; thus as long as steps of less than half a revolution are demanded the shaft can be driven round indefinitely. The final electrical accuracy of positioning will be that obtainable for one revolution, although many revolutions may have taken place.

In the extended analogue unit 10 wipers are used fixed to the shaft. The stores units select the positions and interpolation is carried out by the normal parabolic interpolator unit. A simplified circuit of the extended position analogue unit is shown in Figs. 8a and b. The circuit is similar to the normal position analogue unit circuit shown in Fig. 4. The final switch has however 10 wipers equally spaced and the centre point of the input toroid is earthed. The 10 leads from the wipers pass to the stores units and replace the 10 wires from the transformer T1 of Fig. 2. The stores units are connected to the interpolator in the normal manner. In the single range analogue system the difference between the demand signal and the feedback signal is developed across a transformer in the servo amplifier. In the extended range system this difference is produced mechanically between the motion of the interpolator shaft and the motion of the analogue unit shaft. The output from the interpolator measured relative to the centre point of T1 (Fig. 8a) is therefore the error signal.

The following explanation should help to clarify this point. The output of each of the 10 wipers will be a smoothly varying voltage as they pass from one end of the transformer T1 to the other, with an abrupt jump as they pass over the junction point. In the stores unit the first digit relay tree selects one of the 10 wipers. The other digit relay trees then produce an intermediate voltage between the wipers. This condition is illustrated in Fig 8b. It will be seen that as the interpolator high-speed switch

Fig. 10 Knee-type machines are not of ideal construction for automatic control, and a better machine in this respect is the Cincinnati Hydro-Tel



rotates, the servo system causes the 10 wiper switch to rotate so as to keep the interpolator output electrically opposite the centre tap of the extended analogue toroid T1.

The maximum point spacing must not exceed half the extended analogue range. Thus if this is 10 in. the maximum point spacing is 5 in. and in practice it should be kept below this figure.

If a 10 in. range is extended to cover a 100 in. system there will be 10 ambiguous positions. These can be resolved by a coarse single range system, but on contouring it is usually sufficient to bring the motion automatically to near the zero point, for example by using microswitches. The fine range can then be switched in and the motion will position accurately to zero.

2.10 Applications

The contouring system has been fitted to various types of machines. The first ones to be controlled were knee-type vertical milling machines and one of these is shown in Fig. 9. This machine is controlled on the X and Y motions only. The motions are driven by recirculating ball nut and leadscrew with the position analogue unit mounted on the leadscrew. Knee-type machines are not of ideal construction for automatic control. A better machine in this respect is the Cincinnati Hydro-Tel (Fig. 10). The Hydro-Tel is a bed-type machine hydraulically-operated. The motions are driven from pistons and cylinders controlled from electrohydraulic valves. The position analogue units are driven from precision racks. The machine control has zero shift and cutter diameter compensation facilities.

In conjunction with the Cincinnati Milling Machine Co the system has been fitted to a large skin milling machine built for the Air Material Command of the USAF. This machine is of the fixed-bed moving-gantry type with two cutter heads carried on the cross-rail. The work-table is 8 ft wide and 30 ft long. The overall length of the machine bed is 39 ft 9 in. and the gantry can be traversed 31 ft 6 in. The cutter heads are moved along the cross-rail by recirculating ball leadscrews while the gantry is driven from a rack and pinion system. The machine is illustrated at the top of the first page of this part of the article.

2.11 Accuracy

The electrical accuracy of the system is 1/50,000 of the reference range. Thus for reference ranges of 100 in., 30 in. and 10 in. the accuracy is $\pm 0{\cdot}002$, $\pm 0{\cdot}0006$ and $\pm 0{\cdot}0002$ in. respectively. By use of the extended analogue principle the accuracy of the 10 in. reference range can be obtained on the longer ranges.

The accuracy of the work-pieces obtained from the machines will depend on the cutting techniques employed and the structural design of the machine. In general on the small machines it has been found that an additional inaccuracy of from $\pm 0{\cdot}001$ to 0·002 in. exists.

To be continued

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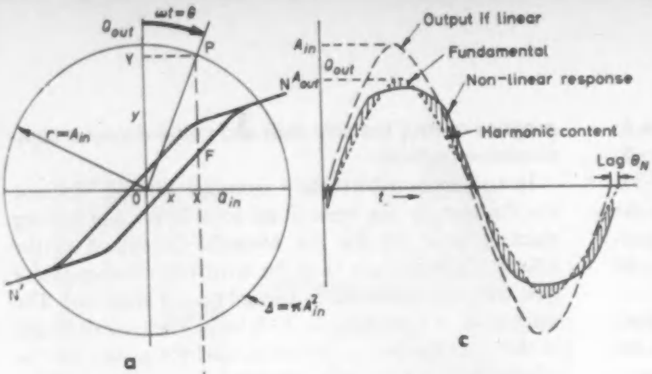

by **P. J. BHATT, B.SC. (ENG.), PH.D., A.M.I.E.E., A.M.I.MECH.E.**

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Describing functions for non-linear servo systems

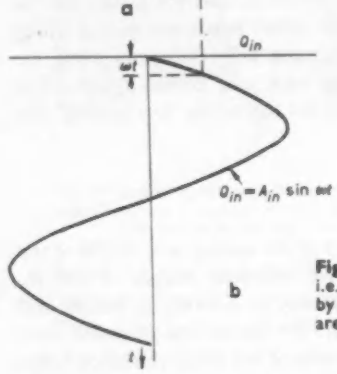


Fig. 1 The principle of quasi-linearization, i.e. representing the non-linear response by its fundamental component. The shaded area indicates the extent of the inaccuracy involved in the approximation.

THE LINEAR THEORY OF SERVO CONTROL IS BASED ON THE assumption that all physical phenomena within the system can be defined by linear laws, e.g. Ohm's law ($V = iR$), Faraday's law ($v = Ldi/dt$) and Newton's law $\left(P = M\dfrac{d^2x}{dt^2}\right)$.

Linear systems

A system is said to be linear if it conforms to the principle of superposition, viz the response of the system to a change which is the sum of two changes can be evaluated by summing the effects that would have been caused if each change had acted separately, i.e.

$$f(x_1 + x_2) = f(x_1) + f(x_2)$$

The behaviour of such a system can be represented by an integro-differential equation with linear coefficients, e.g.

$$v = iR + L\frac{di}{dt} + \frac{1}{C}\int idt$$

The equation contains only the first power of the dependent variable and its time-derivatives with no cross-products between them. The assumption of linearity enables one to use the concept of equivalent impedances, star-delta transformations, Thévenin's theorem and other such simplifying techniques. In a linear servo all aspects of the behaviour of the system can be easily predicted from the equation of motion of the system. In particular, rules of thumb have been evolved to specify the magnitude of the maximum overshoot, the settling time, etc, of the response under any disturbance.

Non-linear systems

In a large number of control systems these linear techniques have led to solutions which have shown something of the true characteristics of the system. However, certain systems give rise to phenomena which cannot be accounted for by linear techniques, e.g. a system which is stable to small disturbances may be found to distort the effects of larger disturbances. On the other hand a system designed to give high damping ratios and low speeds of response to large signals may be found to be underdamped for inputs that are not large. The performance of these systems under one condition cannot be predicted from experience of its behaviour under other conditions. In such cases the principle of superposition is not valid and the system is classed as non-linear.

Several types of non-linearity occur in practice. These may be inherent (e.g. saturation, backlash and hysteresis) or artificial (e.g. current limits in electrical systems, overlaps on hydraulic valves). In different systems these non-linearities contribute different types of peculiarities. With a constant input signal, the system may execute stable oscillations, a characteristic which finds useful applications in electrical oscillators. With other systems the output may be found to be a multiple or a sub-multiple of the driving frequency. However, in practically all servo control problems, the system will be found to respond at the same frequency as the input signal. The method discussed in this article refers to this class of non-linearities only.

Quasi-linearization

In evaluating the performance of such servo systems, it is general to distinguish between those elements which can be considered to be linear and those parts of the system which are essentially non-linear. The linear elements will be found to be dependent on the frequency but not the amplitude of the driving signal. These elements can be defined by their individual transfer functions and all adjoining linear elements can be treated together as a single linear part. Each non-linear part will be found to be independent of input frequency but dependent on the amplitude of the signal. If there is more than one non-linearity they can be treated together by

defining a composite non-linear part, which may be dependent on both amplitude and frequency of the input. The following procedure assumes that there is only one non-linear element in the system.

When a sinusoidal signal is applied to a non-linear element the response will be a distorted wave. If the overall response is essentially sinusoidal, it is reasonable to assume that the harmonics do not make any material contribution towards the system performance. This assumption of dominant fundamental enables one to define a quasi-linear transfer function or describing function for the element, and permits stability criteria well established in linear theory to be extended to non-linear systems. Several studies, both analytical and experimental, have proved that satisfactory solutions can be obtained by this method of approximation. The technique is referred to as quasi- or harmonic-linearization.

The describing function

The diagrams of Fig. 1 demonstrate the principles of quasi-linearization. The non-linearity represented is that of magnetic hysteresis and is double-valued, the output for decreasing input signals being higher than that for the same amplitude of increasing inputs. The input sinusoid is $Q_{in} = A_{in} \sin \omega t$, whilst the effective output is represented by the Fourier fundamental of the output wave. Let this be represented as

$$Q_{out} = A_{out} \sin(\omega t + \theta_N)$$

where θ_N is the effective phase shift (lagging in Fig. 1) and where the effective gain is $W_N = A_{out}/A_{in}$. The describing function of the non-linear element is defined as

$$K_N G_N = p_N + jq_N$$

where $p_N = W_N \cos \theta_N \qquad q_N = W_N \sin \theta_N$

The values of p_N and q_N are defined by the Fourier integrals

$$A_{in} p_N = \frac{1}{\pi} \int_0^{2\pi} Q_{out} . \sin \omega t . d(\omega t)$$

and

$$A_{in} q_N = \frac{1}{\pi} \int_0^{2\pi} Q_{out} . \cos \omega t . d(\omega t)$$

The values of p_N and q_N have been evaluated for most of the non-linearities commonly encountered in servo controls, but these expressions are difficult to remember (*1*). Furthermore, if the non-linearity is not standard but is defined graphically by a number of experimentally determined points, the evaluation of the describing function becomes extremely complex.

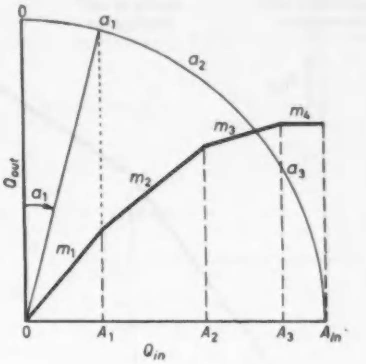


Fig. 2 A single-valued pseudo-linear system. The non-linear characteristic is approximated by straight-line segments

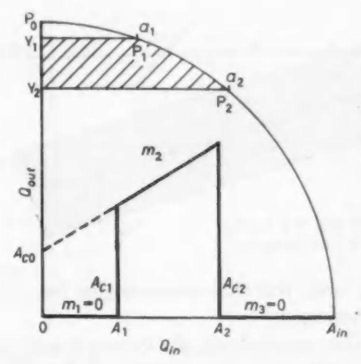


Fig. 3 A basic element of a pseudo-linear characteristic. A non-linearity such as Fig. 2 can be considered to be composed of a number of such elements adjacent to one another

(A_1 and A_2 should be directly beneath a_1 and a_2 respectively as in Fig. 2)

The technique presented in this article simplifies the procedure and enables one to evaluate the in-phase and quadrature components in a quick, yet effective manner (*2*).

Pseudo-linearization

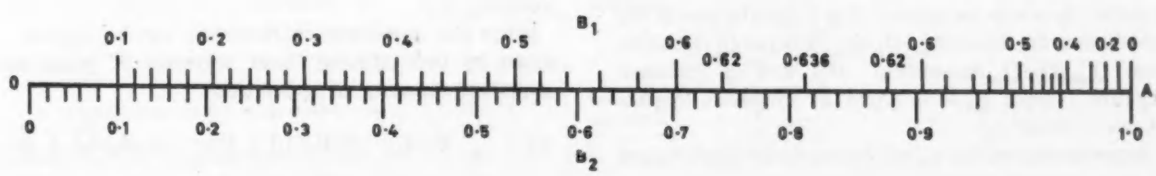
To begin with, the characteristic of the non-linear element is defined by a number of linear segments, each segment being defined by its incremental gain, or gradient, m_r. The resultant output from the system is thus built up of a number of segments of sine waves. In general, two to three values of m_r will be sufficient. In effecting this segmentation the skew-symmetry of the characteristic must not be lost, i.e. care must be taken to ensure that $Q_{out}(\omega t) = - Q_{out}(\omega t + \pi)$.

Fig. 2 shows a single-valued pseudo-linear system. As the characteristic is symmetrical only one half is shown. Let there be n segments of gradients $m_1, m_2 \ldots m_r \ldots m_n$, the points of intersection being given by input amplitudes of $A_1, A_2 \ldots A_r \ldots A_n$. Let

$$A_r = A_{in} \sin a_r$$

The angle a_r is acute (0 to $\pi/2$) and is referred to as the 'corner angle' at which the output changes abruptly from the segment of gradient m_r to the next (gradient m_{r+1}). Each of the $(n - 1)$ intersections is associated with such a

Fig. 4 The B-function scale. Note that B_1 has a maximum value of 0.636 and then decreases to zero at $A_r = A_{in}$. For A_r less than 1/10 A_{in}, $B_1/A_r = 1.27/A_{in}$



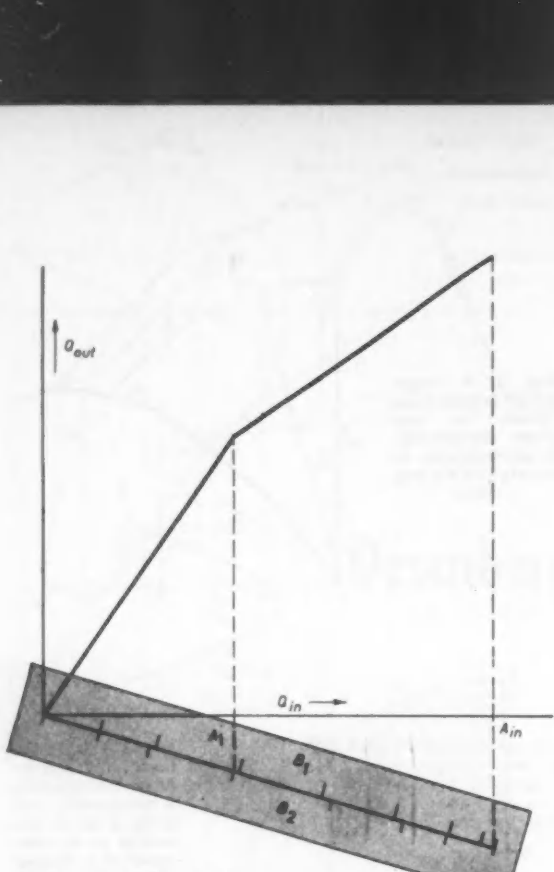


Fig. 5 How the scale of Fig. 4 is used to read B_1 and B_2 at A_1 for an input A_{in}

corner angle. It is observed that these angles become smaller as A_{in} is increased.

If all the values of m_r are defined, the system is said to be 'continuous'. However, non-linear characteristics may have $m = \infty$, thus giving rise to a 'jump' in the output values for a small change in the input signal. This is referred to as a 'discontinuity.' If there is no break in the characteristic the discontinuity is said to be 'finite', e.g. the non-linearity representing Coulomb friction has a finite discontinuity at the origin. The magnitude of the discontinuity will be represented by A_c.

The quadrature component

The value of the quadrature component q_N of the describing function has been defined as

$$A_{in}q_N = \frac{1}{\pi}\int_0^{2\pi} Q_{out}\cos\omega t\,.\,d(\omega t)$$

Noting that $\cos\omega t\,.\,d(\omega t) \equiv d(\sin\omega t)$

we may state the value of q_N as

$$q_N = \frac{1}{\pi A_{in}^2}\int_{\omega=0}^{\omega=2\pi} Q_{out}\, d(A_{in}\sin\omega t) = \frac{1}{\Delta}\int_{\omega=0}^{\omega=2\pi} Q_{out}\, dQ_{in}$$

where $\Delta = \pi A_{in}^2$ = area of the circle radius A_{in}

The integration represents the area subtended on the Q_{in}-axis by the point F on the non-linear characteristic (Fig. 1) as it traverses the characteristic over one cycle, 0 to 2π. This cyclic integration thus yields the area of the hysteresis loop. Since Q_{out} [Q_{in}(Q_{in} increasing)] is smaller than Q_{out} [Q_{in}(Q_{in} decreasing)], this area is reckoned negative. Hence $q_N = -$ (Area of hysteresis loop) $\div$ (Areas of circle A_{in}).

It can be asserted that q_N will be zero for all single-valued systems. For double-valued systems, if the hysteresis loop can be approximated by a parallelogram (or two halves of it), q_N will be given by $-2A_dA_{cm}/\Delta$, where A_d is the width of the loop measured along the Q_{in} axis and A_{cm} is the mean value of Q_{out} within the loop.

The in-phase component

To determine p_N a similar interpretation is made of its Fourier integral. Noting that $\sin\omega t\,.\,d(\omega t) \equiv -d(\cos\omega t)$ we have

$$p_N = \frac{-1}{\Delta}\int_{\omega t=0}^{\omega t=2\pi} Q_{out}\, d(A_{in}\cos\omega t) = \frac{-1}{\Delta}\int_{\omega t=0}^{\omega t=2\pi} Q_{out}\, dy$$

If the circle A_{in} is drawn (Fig. 1) the value of $A_{in}/\cos\omega t$ corresponding to the point F will be given by the ordinate y = XP. The angle YOP is equal to the angle ωt.

To derive a general result the pseudo-linear characteristic is divided into a number of basic elements as in Fig. 3. This basic characteristic is drawn with a dead space from 0 up to A_1 ($m_1 = 0$) and a jump A_{c1} at this point. A linear segment of gradient m_2 follows. At the point A_2 the output abruptly decreases to zero and remains at this value until Q_{in} reaches its maximum value A_{in} ($m_3 = 0$). For this non-linearity the integral can be evaluated (see Appendix) to give

$$p_N = \frac{A_{c1}}{A_1}B(A_1) + m_2[B_2(A_2) - B_2(A_1)] - \frac{A_{c2}}{A_2}B_1(A_2)$$

The diagram of Fig. 4 shows a scale of B-functions. To evaluate p_N the scale is placed with the end 0 at the origin; the scale is then adjusted (Fig. 5) such that the other end A_{in} falls along the ordinate representing the maximum value of input sinusoid. The corners of the non-linearity are projected on the scale to identify the respective values of B_1 and B_2. By multiplying the values B_1, B_2 by the values of the parameters (A_{c1}/A_1) and m_2, the value of p_N is readily determined for any value of A_{in}.

Any pseudo-linear system can be built up of a number of these basic elements. If the non-linearity is continuous, the A_{c2} of one element will be equal to the A_{c1} of the element that follows immediately. When the system is discontinuous the A_{c1} will be bigger (or smaller) than the preceding A_{c2}.

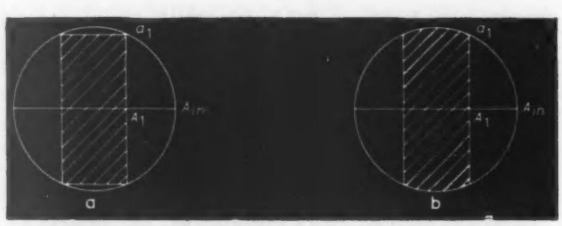


Fig. 6 The B-functions: **a)** B_1 corresponding to a discontinuity at A_1; and **b)** B_2 corresponding to a corner at A_1. The circle has a radius equal to the input amplitude A_{in}

When the non-linear characteristic can be approximated by two adjacent linear segments of gradients m_2 and m_3, the value of p_N becomes

$$p_N = \frac{A_{c1}}{A_1}B_1(A_1) - m_2B_2(A_1) + (m_2 - m_3)B_2(A_2) + m_3$$

The third possible corner is assumed to be at $\omega t = \pi/2$; here $B_1(A_{in}) = 0$, $B_2(A_{in}) = 1$ and $m_4 = 0$. For the general n-segmented non-linearity, this result becomes

$$p_N = \frac{A_{c1}}{A_1} B_1(A_1) + \sum_{r=1}^{r=n}(m_r - m_{r+1})B_2(A_r) + m_n$$

where a_r is the corner angle at which the output changes from the segment m_r to the segment m_{r+1}; m_n is the gradient of the final segment ($a_n < \omega t < \pi/2$); and m_1 is the gradient of the non-linearity at the origin ($m_1 = 0$ in Fig. 3).

For a dual-valued system the integration must be considered over a half cycle. Alternatively, p_N can be considered to be the mean of the two values obtained when the integration is carried out over each half quadrant, i.e. $p_N = \frac{1}{2}p_N(\dot{Q}_{in}>0) + \frac{1}{2}p_N(\dot{Q}_{in}<0)$.

If there is more than one discontinuity there will be a term in B_1 at each discontinuity.

The values of p_N for various types of non-linear systems are listed in the accompanying table.

APPENDIX

The in-phase component p_N

Referring to Fig. 3, the instantaneous value of Q_{out} is given by

$$Q_{out} = 0 \text{ for } 0 < Q_{in} < A_1 \text{ and } A_2 < Q_{in} < A_{in}$$

and $$Q_{out} = A_{c1} + m_2(Q_{in} - A_1) \qquad \text{for } A_1 < Q_{in} < A_2$$
$$= A_{c0} + m_2 Q_{in}$$

where $$A_{c0} = A_{c1} - m_2 A_1 = A_1\left(\frac{A_{c1}}{A_1} - m_2\right)$$

and also $$A_{c0} = A_{c2} - m_2 A_2 = A_2\left(\frac{A_{c2}}{A_2} - m_2\right)$$

Since the characteristic is single-valued the integration indicated above need be taken over only one quadrant, i.e.

$$p_N = -\frac{4}{\Delta}\int_{\omega t=0}^{\omega t=\pi/2} Q_{out}\,dy = -\frac{4}{\Delta}\int_{Q_{in}=A_1}^{Q_{in}=A_2}(A_{c0} + m_2 Q_{in})dy$$
$$= -\frac{4}{\Delta}A_{c0}(OY_2 - OY_1) + \frac{4m_2}{\Delta}\int_{Q_{in}=A_2}^{Q_{in}=A_1} Q_{in}\,dy$$

Since $$A_1OY_1 = (A_{in}\sin a_1)(A_{in}\cos a_1) = \tfrac{1}{2}A^2_{in}\sin 2a_1$$

where a_1 is the corner angle at A_1

therefore $$A_{c0}OY_1 = \tfrac{1}{2}\left(\frac{A_{c1}}{A_1} - m_2\right)A^2_{in}\sin 2a_1$$

Similarly $$A_{c0}OY_2 = \tfrac{1}{2}\left(\frac{A_{c2}}{A_2} - m_2\right)A^2_{in}\sin 2a_2$$

where a_2 is the corner angle at A_2

The integral of $Q_{in}dy$ in the expression for p_N represents the area $Y_1P_1P_2Y_2$

$$= \text{area of segment } P_0P_2Y_2 - \text{area of segment } P_0P_1Y_1$$
$$= (\tfrac{1}{2}a_2A^2_{in} - \tfrac{1}{4}A^2_{in}\sin 2a_2) - (\tfrac{1}{2}a_1A^2_{in} - \tfrac{1}{4}A^2_{in}\sin 2a_1)$$

Thence, collecting the terms in $m_2A^2_{in}\sin 2a$, we have

$$p_N \doteq -\frac{2}{\pi}\left(\frac{A_{c2}}{A_2}\sin 2a_2 - \frac{A_{c1}}{A_1}\sin 2a_1\right) + \frac{m_2}{\pi}(2a_2 + \sin 2a_2 - 2a_1 - \sin 2a_1)$$
$$= \frac{A_{c1}}{A_1}B_1(A_1) + m_2[B_2(A_2) - B_2(A_1)] - \frac{A_{c2}}{A_1}B_1(A_2)$$

where $$B_1(A_r) = \frac{2\sin 2a_r}{\pi} \quad \text{and} \quad B_2(A_r) = \frac{2a_r}{\pi}\left(1 + \frac{\sin 2a_r}{2a_r}\right)$$

These functions represent the two areas indicated in Fig. 6

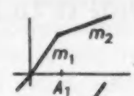
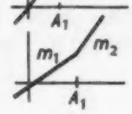
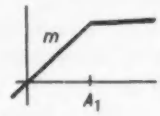
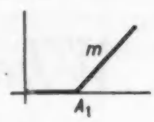
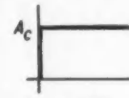
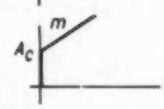
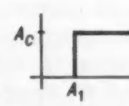
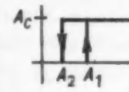
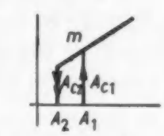
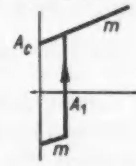
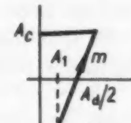
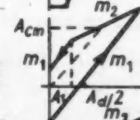
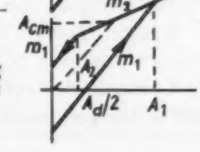
When $A_r = 0$ $\quad \frac{A_{c0}}{A_0}B_1(0) = \frac{4}{\pi}\cdot\frac{A_{c0}}{A_{in}} = \frac{1{\cdot}27\,A_{c0}}{A_{in}}$ and $B_2(0) = 0$

When $A_r = A_{in}$ $\quad B_1(A_{in}) = 0$ and $B_2(A_{in}) = 1$

References

1. Grief, H. D.: 'Describing function method of servomechanism analysis applied to most commonly encountered non-linearities' *Trans. A.I.E.E.*, 1953, 72, Pt. 2 pp 243–248
2. Bhatt, P. J.: Ph.D. Thesis, Nottingham University, 1958.

TABLE I. DESCRIBING FUNCTIONS

Non-Linearity	Characteristic	The in-phase component	The quadrature component
Soft spring		$(m_1 - m_2)B_2(A_1) + m_2$	0
Hard spring		$-(m_2 - m_1)B_2(A_1) + m_2$	0
Limitation		$mB_2(A_1)$	0
Dead space		$m - mB_2(A_1)$	0
Contactor		$1{\cdot}27\frac{A_c}{A_{in}}$	0
Friction		$1{\cdot}27\frac{A_c}{A_{in}} + m$	0
Contactor with dead space		$\frac{A_c}{A_1}B_1(A_1)$	0
Contactor with dead space and hysteresis		$\frac{1}{2}\left[\frac{A_c}{A_1}B_1(A_1) + \frac{A_c}{A_1}B_1(A_2)\right]$	$-\frac{0{\cdot}636\,A_c(A_1 - A_2)}{A^2_{in}}$
Complex contactor		$\frac{1}{2}\left[\frac{A_{c1}}{A_1}B_1(A_1) + \frac{A_{c2}}{A_2}B_1(A_2)\right] - \frac{m}{2}\left[B_2(A_1) + B_1(A_1)\right] + m$	$-\frac{(A_{c1} + A_{c2})(A_1 - A_2)}{\pi A^2_{in}}$
Over-lap		$\frac{A_c}{A_1}B_1(A_1) + m$	$-1{\cdot}27\frac{A_c \cdot A_1}{A^2_{in}}$
Backlash		$\frac{m}{2}\left[1 + B_2(A_1)\right]$	$\frac{0{\cdot}636A_dA_c}{A^2_{in}}$
Non-saturating hysteresis		$m_2 + \frac{m_1 - m_2}{2}\left[1 + B_2(A_1)\right]$	$-\frac{0{\cdot}636A_dA_{cm}}{A^2_{in}}$
Saturating hysteresis		$m_2 + \frac{m_1 - m_2}{2}\left[B_2(A_1) + B_2(A_2)\right]$	$-\frac{0{\cdot}636A_dA_{cm}}{A^2_{in}}$

PART

7

—The final article in the Cambridge series on fundamentals

What is control engineering?

by **C. M. BURRELL,** M.A., B.Sc., A.M.I.E.E.
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IN MOST CONTROL SYSTEMS THE DESIGNER CHOOSES CERTAIN component parts on grounds of availability, cost, convenience and other practical issues rather than theoretical ones. He may also have to decide on the broad scheme of dependence, before performance (i.e. stability and accuracy) is considered. Thus his task is to improve or compensate the performance of a system in which the broad scheme of dependence and some elements are invariant. This is normally accomplished by designing a suitable frequency-dependent element or elements connected to the system in one or more of three ways:

1 In cascade in the forward path
2 In a subsidiary feedback path over either the whole or part of the forward path transfer function
3 In a subsidiary feed-forward path over part or all of the forward path transfer function.

Examples showing how system stability can be improved by using the first two methods mentioned above, have been given in Part 6 (December), but usually system compensation is a more difficult and involved problem than system stabilization. We shall discuss the nature and solution of the compensation problem in this article.

The problem of compensation

The function of most control systems is to control an output quantity so that it follows the input quantity within some specified error. Perfect following (zero error at all instants) implies that the transfer function relating input to output is unity. In theory this ideal condition could be achieved by inserting a cascade element having a transfer function $W_1(p)$ equal to the reciprocal of the transfer function $W_2(p)$ of the invariant part of the system and keeping the open-loop gain $K \gg 1$ (see Fig. 1). Unfortunately, severe practical difficulties prohibit the use of this form of compensation.

The general form of the transfer function $W_2(p)$ for the fixed part of the system is:

$$W_2(p) = \frac{K_2 \prod_{j=1}^{m} (1 + pT_j)}{p^l \prod_{k=1}^{n-l} (1 + pT_k)} \qquad . \ . \ . \ (1)$$

Since $W_2(p)$ is a physical system*, $n \geqslant m$.

The reciprocal function $W_1(p)$ is not physically realizable, except when $n = m$, and has to be approximated. Furthermore, the product of $W_2(p)W_1(p)$ can be equal to unity only if the poles of $W_1(p)$ cancel with the zeros of $W_2(p)$, and vice versa. This procedure relies on the choice of accurate and stable components in both parts of the system represented by $W_1(p)$ and $W_2(p)$; perfect cancellation is impossible in practice and component drift can produce very imperfect cancellation at some frequency if a pole or zero lies near the imaginary axis of the complex p-plane.

Inertia causes complications

A third and perhaps more serious objection to perfect compensation arises out of the fact that all physical systems possess inertia (by this we mean simply $n > m$ in equation 1). Thus very large instantaneous power may

* If $n < m$ the system output tends to an infinite value as the frequency tends to infinity, and this condition is not physically realizable. In fact, for all physical systems $n > m$ so that the output tends to zero as the frequency tends to infinity. The case $n = m$ is allowed in the theory as the boundary case, since very close approximation to transfer functions with $n = m$ can be obtained.

be needed to accelerate this inertia so that it can respond with zero error under the influence of rapid changes of input; for this to be possible, component parts (e.g. amplifiers, motors) must be designed to handle large signals without saturating or overheating; in practice provision for the control system to consume very large instantaneous powers may result in an uneconomical design. Thus it is seen that a restriction on maximum available power must be accepted, and often occurs naturally because of the presence of a saturating element in the invariant part of the control system.

Disturbances in the system will also upset the proposed idealistic approach. Disturbances can be looked upon as a limitation on the obtainable accuracy, just as power limitation inhibits perfect performance.

The problem of compensation is complicated by considerations of economy, accuracy, noise and power limitation. A solution to the problem often means finding the best compromise for the system and its input and involves the design of the most economic system that satisfies the error specification as nearly as possible, in spite of the inherent restrictions imposed by the input and the invariant part of the system.

Choosing a performance criterion

Since the idealistic solution giving zero error is disallowed, some criterion of performance is necessary with which the 'goodness' of system performance can be measured. The criterion usually consists of a measure of error. The choice of criterion must depend upon

1 The application
2 The kind of input
3 Convenience

The importance of choosing the right performance criterion for the application is illustrated by the temperature control of open-hearth steel furnaces. The

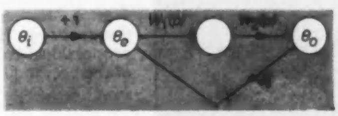

Fig. 1 The dependence diagram of a cascade compensated system

controls used are normally designed to operate with little or no overshoot; this is necessary because in order to shorten the refining time the working temperature is only just below the temperature at which the furnace roof would be seriously damaged. An appropriate criterion of performance in this application might be 'magnitude of first overshoot' to a step change of input.

We must consider also the input signal in choosing a suitable criterion because it is naturally desirable to specify, if possible, the required performance in terms of the response to an input of the same kind that the system will experience. Thus for a step input we could measure:

a The magnitude of first overshoot
b The time taken to settle to within a specified margin of the ultimate value (settling time)
c The offset or difference between the ultimate steady value and the desired value of output (Fig. 2).

These measures of performance are meaningless for any input except a step.

Convenience also influences our choice. Nearly all analytical design methods use the mean-squared-error as a measure of performance, its value being defined by

$$\overline{\theta_e^2} = \lim_{T\to\infty} \frac{1}{2T}\int_{-T}^{T}\left[\theta_o(t) - \theta_i(t)\right]^2 dt$$

where $\theta_o(t)$ is the system output $\theta_i(t)$ is the desired output.

The most compelling reason for this choice is mathematical convenience. In some applications where small errors are of relatively greater importance (e.g. fire control—where a miss is as good as a mile) a criterion based on modulus of error might be more suitable but such a function is non-analytic and leads to mathematical intractability.

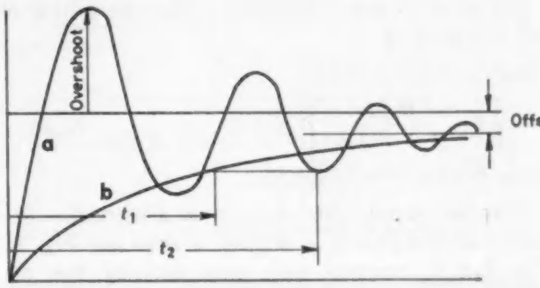

Fig. 2 A measure of performance can be obtained from a system's response to a step input
t_1, t_2 = settling times

System errors

System response errors may be classified under the headings of *transient error* and *steady-state error*. This classification follows logically from the meanings of transient and steady-state response.

The spectra of inputs whose amplitude or higher derivatives of amplitude change rapidly possess very high frequency components, so that the response error is determined largely by the plot of $W_0(j\omega)$ in the region where $|W_0(j\omega)| = 1$ and by its behaviour at higher frequencies. For example a locus diagram which passes near the critical point represents a system with poor stability, and consequently it will have large stability errors due to overshoot (Fig. 2, curve a). Moreover a system with small bandwidth* will also give poor response owing to its sluggishness when responding to rapid changes of input (Fig. 2, curve b). In both cases large errors can be produced in the presence of rapidly varying inputs.

The spectra of inputs whose amplitude or higher derivatives of amplitude change rapidly possess very high importance so that only the low-frequency portion of the frequency response locus is needed to assess the error.

The output open-loop response vector for a system

* Bandwidth may be defined as the width of the frequency band over which the system output is approximately equal to the desired output. Bandwidth is usually measured to the frequency at which the output is 3dB below the desired value.

possessing inertia ($n > m$) will lag further behind the input at high frequencies than it does at low frequencies.

From equation 1 we have:

$$\text{as } \omega \to \infty \quad \varphi = \arg[W_0(j\omega)] \to -(n-m)\frac{\pi}{2}$$

$$\text{whilst as } \omega \to 0 \quad \varphi \to -l^{\pi/2}$$

The insertion of a physically realizable compensation network cannot make the phase lag any less as $\omega \to \infty$, some possible modifications to the open-loop frequency response diagram are:

1 Increase of bandwith
2 Reduction of phase lag near the critical point and possibly at lower frequencies
3 Increase of gain at low frequencies
4 Decrease of gain near the critical point

Increase in bandwidth often means an increase in maximum power level with possible uneconomic consequences.

The error at some frequency ω for the system of Fig. 1 is given by

$$\theta_e(j\omega) = \theta_i(j\omega) - \theta_0(j\omega)$$

$$= \left[1 - \frac{W_0(j\omega)}{1 + W_0(j\omega)}\right]\theta_i(j\omega) = \frac{1}{1 + W_0(j\omega)}\theta_i(j\omega)$$

where $W_0(j\omega) = W_1(j\omega)W_2(j\omega)$

Thus high steady-state accuracy at a particular frequency implies that $[1 + W_0(j\omega)]$ is large (see Fig. 3).

In Part 6, examples were given showing how the frequency response locus could be reshaped to improve system stability by the use of a phase advance network $W_1(p)$ or by velocity feedback. For correct compensation it may be necessary not only to improve system stability by decreasing the gain or introducing phase advance near the critical point but at the same time to increase the gain at the lower frequencies to improve the accuracy. This is effectively increasing the bandwith.

Phase lag compensation of a control system

The position control system which was analysed in Part 3 has an open-loop transfer function of the form $K/[Fp(1 + pJ/F)]$.

The Nyquist diagram for this system is sketched in Fig. 3 and the log gain and phase are plotted against frequency in Fig. 6b for a particular value of open-loop gain $K_0 = K/F$, which has been adjusted to give sufficient steady-state accuracy.

A system with open-loop transfer function of this kind is never truly unstable, the condition of limiting stability being approached as the open-loop gain K_0 approaches infinity. For small steady-state error we must use a large value of gain K_0, which demonstrates that good stability and high steady-state accuracy are conflicting requirements.

To improve system performance we need, therefore, to introduce some form of compensation which alters the shape of the Nyquist diagram near the point $(-1, 0)$ but does not alter it at lower frequencies. The phase lag network shown in Fig. 4 can be used for this purpose since it effectively reduces the open-loop gain at higher frequencies but does not attenuate the lower frequencies, as can be seen from its complex plane plot (Fig. 5) and the log gain and phase plots (Fig. 6a). Figs. 6b and 6c show how the new log gain and phase diagrams may be obtained.

The loss of gain at high frequencies is unfortunately accompanied by greater phase lag, but by correct choice of the time-constants T_1 and T_2 a substantial phase margin (i.e. 180° minus the phase lag at zero decibels) can be obtained.

Error coefficients

Both methods of error specification and criteria of performance are so numerous that they cannot all be mentioned in this article. As we shall be considering methods of compensation in the frequency domain only, it seems reasonable to mention a method of error specification which is capable of interpretation in this domain. The open-loop transfer function can be written always in the form

$$\frac{K_0}{p^l} \cdot \frac{\prod_{j=1}^{m}(1 + pT_j)}{\prod_{k=1}^{n-l}(1 + pT_k)} \quad \ldots \quad (2)$$

When $l = 0$, we call the system a 'type 0' system.
$l = 1$, we call it a 'type 1' system.
$l = 2$, we call it a 'type 2' system, etc.

The open-loop transfer function for the position control system identifies it as type 1.

This classification of the type of system has a direct connexion with system accuracy.

Fig. 3 The error at a frequency ω is inversely proportional to the length of the vector $[1 + W_0(j\omega)]$

The transform of the error for the system shown in Fig. 1 is given by

$$\theta_e(p) = \theta_i(p) - \theta_0(p) = 1 - \frac{W_0(p)}{1 + W_0(p)} \cdot \theta_i(p) = \frac{1}{1 + W_0(p)} \cdot \theta_i(p)$$

where $W_0(p) = W_1(p)W_2(p)$

Therefore for a 'type 0' system, when supplied with constant input or very slowly varying input, the steady-state error is given by

$$\lim_{p \to 0} \theta_e(p) = \frac{1}{1 + K_p}\theta_i \quad \ldots \quad (3)$$

where θ_i is the instantaneous value of the input

$$\text{and} \qquad K_p = \lim_{p \to 0} W_0(p) \quad \ldots \quad (4)$$

is called the positional error coefficient. Usually $K_p \gg 1$

and the error is approximately $1/K_p$ of the input. This steady-state position error, often referred to as offset, can be reduced by making K_p very large.

Offset may be removed completely by using a type 1 system which has a single integration in the loop. The physical explanation is that an integrator can have a constant output only when its input is zero, so that if any offset exists the integrator input will be non-zero and its output value will change until the offset is removed.

The steady-state error θ_0 for this type 1 position control system when following a ramp input is easily found* by integrating the response to a step of amplitude A:

$$\theta_0 = A\left[\frac{s_2}{s_1 - s_2}e^{s_1 t} + \frac{s_1}{s_2 - s_1}e^{s_1 t} + 1\right] \quad . \; . \; . \; (5)$$

$$\text{where} \quad W_0(p) = \frac{\theta_0(p)}{\theta_i(p) - \theta_0(p)} = \frac{K}{Fp(1 + pJ/F)} \quad . \; . \; (6)$$

Integrating both sides of this equation and using the fact that $\theta_i = \theta_o = 0$ when $t = 0$, we have, for a ramp input,

$$\theta_0 = A\left[t - \frac{s_1 + s_2}{s_1 s_2}\right] = A\left[t - \frac{1}{K_0}\right] \quad . \; . \; . \; (7)$$

where $K_0 = K/F$ and $\theta_i = At$.

Therefore the steady-state velocity error is equal to

$$\frac{A}{K_0} = \frac{1}{K_0}\cdot\frac{d\theta_i}{dt} \quad . \; . \; . \; (8)$$

This error is small for large values of K_0.

The velocity error coefficient is defined as

$$K_v = \lim_{p \to 0} pW_0(p) \quad (= K_0 \text{ for a type 1 system}) \quad . \; . \; . \; (9)$$

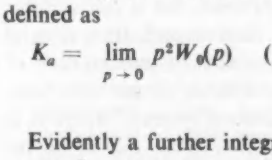

Fig. 4 A phase-lag network $\frac{E_o}{E_i} = \frac{1 + pT_1}{1 + pT_2}$, where $T_1 = CR_2$ and $T_2 = C(R_1 + R_2)$

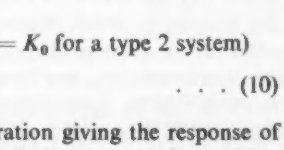

Fig. 5 The complex-plane plot for the phase-lag network of Fig. 4

Similarly the acceleration error coefficient may be defined as

$$K_a = \lim_{p \to 0} p^2 W_0(p) \quad (= K_0 \text{ for a type 2 system}) \quad . \; . \; . \; (10)$$

Evidently a further integration giving the response of a type 1 system to a parabolic input must give an error which is proportional to time becoming infinite as $t \to \infty$. In fact it may be shown that a type l system with an input of the form $\theta_i(t) = At^v/v!$ will have an ultimate steady-state error equal to

$$A/K_0 \text{ for } v = l; \quad 0 \text{ for } v<l; \quad \infty \text{ for } v>l$$

where K_0 is the open-loop gain.

More precisely when $v>l$ the error tends to infinity as $t \to \infty$ and the error is a function of time as $t \to \infty$, of the form

$$\theta_e(t) = \left[\frac{C_l t^{v-l}}{(v-l)!} + \frac{C_{l+1}t^{v-l-1}}{(v-l-1)!} + \ldots + C_{v-1}t + C_v\right]A \quad . \; . \; . \; (11)$$

which is a special case of the equation

$$\theta_e(t) = [C_0\theta_i(t) + C_1\theta_i'(t) + C_2\theta_i''(t)\ldots] \quad . \; . \; . \; (12)$$

where for a system type l the first $(l - 1)$ coefficients are zero.

This expression for error is valid for large values of t (i.e. steady-state errors) and is extremely useful for finding the instantaneous error for any arbitrary input under steady-state conditions.

* See Part 3

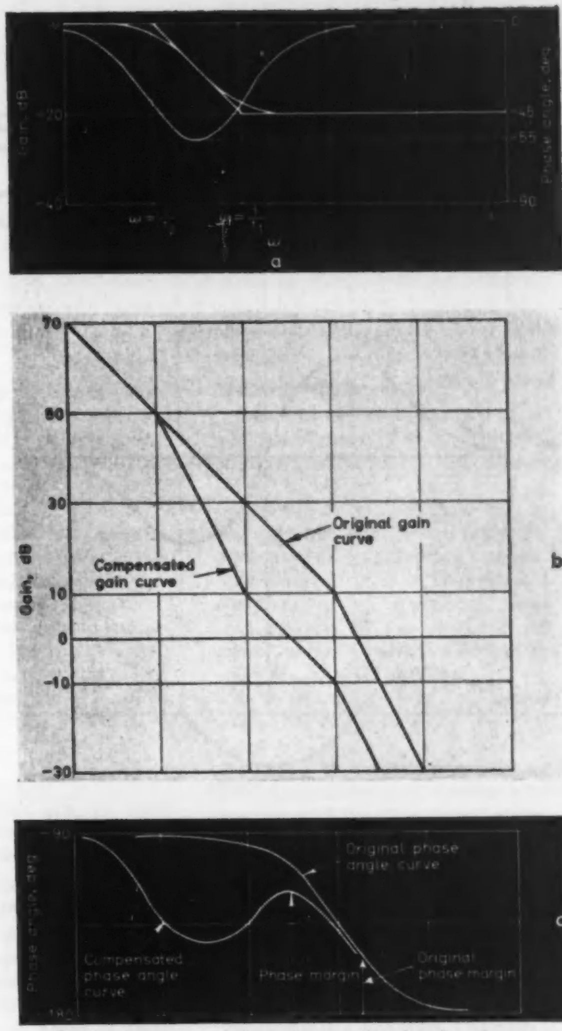

Fig. 6 a Log gain and phase diagrams for the phase-lag network of Fig. 4 when $T_2 = 10T_1$
b Asymptotic approximation to the log gain plot for the position control system, both before and after compensation
c Phase angle diagram, before and after compensation

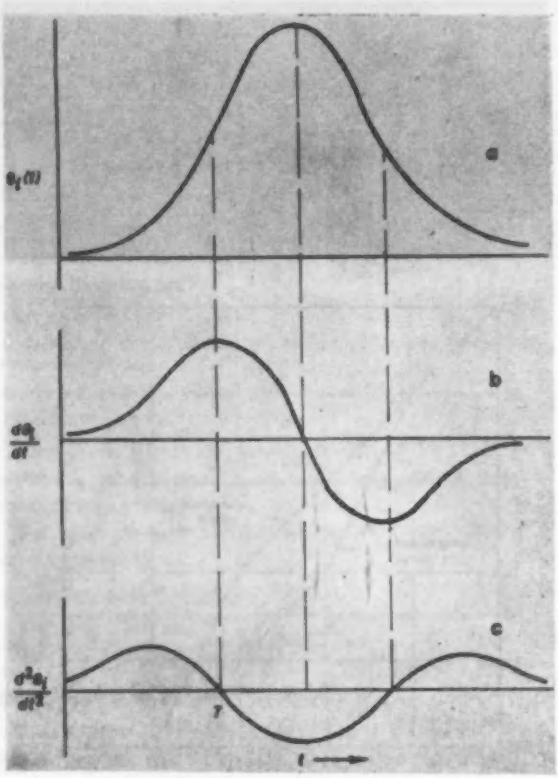

Fig. 7 a The elevation of an aircraft in straight and level flight shown plotted against time
b The first derivative of the aircraft elevation
c The second derivative of the aircraft elevation

The transform of the above equation (putting p in place of d/dt) becomes

$$\theta_e(p) = C_0\theta_i(p) + C_1 p\theta_i(p) + C_2 p^2\theta_i(p) + \dots \qquad \dots (13)$$

Therefore

$$\frac{1}{1 + W_0(p)} = \frac{\theta_e(p)}{\theta_i(p)} = C_0 + C_1 p + C_2 p^2 + \dots \qquad \dots (14)$$

and the coefficients can be found by using the relations

$$C_k = \left\{\frac{d^k}{dp^k}\left[\frac{1}{1 + W_0(p)}\right]\right\}_{p=0} \qquad \dots (15)$$

These coefficients can all be expressed explicitly in terms of the system parameters.

Compensating a radar system

We consider as an example the elevation of a radar dish tracking an aircraft in straight and level flight. The value of the elevation plotted against time is shown in Fig. 7a*. This signal will be the desired output response of the dish elevation control system $\theta_i(t)$.

Normally the radar-directed anti-aircraft gun will be fired before the elevation reaches its maximum. At the time of firing the dish elevation must be accurately aligned. Investigation of the derivatives of this time function shows that the dish acceleration is zero at time $t = T$. If this instant is chosen as the firing time, acceleration errors will be zero irrespective of the system type. A type 1 system will give zero displacement error; thus the velocity error is the only error of importance (assuming higher derivatives of elevation are negligible), and the error specification will simply involve a statement of the velocity error constant. The position control system described earlier would be a suitable system for this application, for the method of compensation described, though not very sophisticated, might enable a sufficiently high velocity coefficient $K_v = K_c$ to be obtained, consistent with a reasonable phase margin.

* See also Part 3

Conclusion

In this series of articles we have answered the title question only partially, since we have deliberately confined ourselves to principles. Control engineering of course involves also practice and experience, but the practice of control engineering is a subject so broad that it could not have been covered adequately by a short series of articles of this kind.

We have developed the theory of linear control systems with particular emphasis on frequency response methods. Whilst frequency response techniques may be attractive for many applications, it would be wrong to assume either that this is always so, or that the most suitable design method for the solution of a given problem is always obvious. Control engineers seem to be divided in their opinions about the relative merits of the various linear design techniques which are available. The fact that only frequency response methods have been described in these articles does not mean that we favour these methods to the exclusion of all others.

Lack of space and time have also prevented us from dealing with non-linear theory. But we have indicated that non-linearities in a system need not be regarded merely as unfortunate occurrences. It is true that the presence of a non-linear component in a system invalidates linear analysis unless some, often doubtful, assumptions are first made. However the deliberate introduction of non-linear components into an otherwise optimum linear system can give further improvement to the system performance.

Exact analysis of non-linear systems may be very difficult and often impossible, but some approximate methods are available, the most important being the describing-function method of analysis (*1*). The phase-plane method is also of importance, but is not suitable for systems of orders higher than second. Bose (*2*) and others have considered the problem of optimization of non-linear systems, but it is difficult to see how their methods can be applied to control systems, where it is common to find that a restriction exists due to an invariant part of the system.

References

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2. Bose, A. G.: 'A Theory of Non-linear Systems' MIT Research Laboratory of Electronics. Technical Report No. 309, 1956

HOW TO APPLY PRESSURE CHARACTERISTICS OF LINEAR VALVES—4

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The final Data Sheet of a series of four. These are primarily concerned with servovalves although parts are particularly applicable to the design of pressure relief and regulating valves also.

PRODUCTION QUALITY CONTROL TESTS FOR SERVOVALVES

Using the pressure traverse tests previously described, we can measure hysteresis, null shift and threshold. Such tests are used when valve spool position cannot be monitored or when flow testing is difficult, as in some environmental testing. The tests are comparative rather than fundamental because in the stalled condition there are no flow reaction forces within the valve and the normal leakage patterns which contribute to hydraulic lock and stiction are modified.

Hysteresis measurement

A hysteresis curve can be plotted for output pressure P or P_m, against valve deflexion X. The hysteresis displayed will be that of the electromagnetic or other form of drive, plus that of the transmission, moving element and any springs, modified as above, plus that of the measuring instruments. This last will often be comparable with that of the valve in the absence of special care.

With a good zero-lapped valve a highly sensitive adjustment to the input will be necessary to maintain output pressures intermediate between supply and exhaust. Too much drifting may occur when plotting from pressure gauge readings, making the use of pressure pick-offs and oscillographic display essential. The very lowest frequencies should be used with this form of test however. It is easy to show that if any overlap is present the compressibility of the oil around and near the valve spool gives rise to substantial hysteresis in the output pressure at frequencies as low as 5 c/s or less.

Null shift measurement

A very sensitive indication of null shift can be obtained by using a small sinusoidal input to give a hysteresis loop display with a small pressure swing about the mean output pressure. Care is again needed to minimize drift in the pick-off units and driving amplifiers and the oscilloscope. If the valve is subjected to temperature change, g-loading or supply pressure change the loop will drift up or down and the control signal change required to correct this can be measured. Because of the drift problem the environmental changes must be made as quickly as possible, consistent with achieving a steady state.

For the four-way valve these measurements are easy with a reliable differential pressure pick-off, but measurement of the null shift in a three-way valve due to supply pressure is more difficult. P must be compared with $P_s/2$ and so the supply pressure must also be displayed, with suitable scaling down, to serve as a base line.

The threshold test

Below the threshold level, the hysteresis loop is a straight line and when a loop is incipient the length of the line gives the stall pressure threshold signal.

Imperfections affecting the pressure characteristics of zero-lapped valves

The influence on the pressure output of unintentional over- or under-lap was touched upon in Data Sheet 6 (December). The imperfections in zero-lapped valves also take other forms of comparable significance. The pressures in the output ports are governed by the flows entering and leaving the output port chambers. Ideally such flows would always pass through the oil motor also, and it is easy to see that, on the pressure diagram, leakage past the oil motor is synonymous with a moving motor.

Internal leakage flows have exactly the same effect if they bypass the output ports, shifting the working point onto a curve of different q_m. Radial clearance between spool and bore, out-of-square or blunt metering edges all contribute to such internal leakage. Consideration of the $q-p-\gamma$ plots shows that when $q_m = 0$ (i.e. in the stalled condition) and when the valve deflexion X is positive, P and P_m are high and the internal leakage flow has the same effect on the port pressures as a positive value of q_m. The working point on the pressure output diagram is thus displaced to the right. Similarly, when X is negative, the working point is displaced to the left. The general effect is to lower the slope $(\partial p/\partial \gamma)_q$ just as under-lap does.

The over-lapped valve

Considerations such as radial clearance and bluntness of edges particularly affect the treatment of over-lapped valves of the sliding type. Others, such as poppet valves, may be relied upon to seal perfectly for practical purposes. Their pressure characteristics are therefore similar to those in Data Sheet 4 (October), but with the (q_m + ve) curves shifted bodily to the right and the (q_m − ve) curves moved to the left, by the amount of the over-lap.

It is difficult to offer any general theory for sliding valves on the other hand. One reason is the complication introduced by radial clearance as the flow becomes very small. Another is the occurrence of the little-studied transitional region between the turbulent flows of the open valve ($\propto \Delta P^{\frac{1}{2}}$) and the viscous flows in the heavily over-lapped range ($\propto \Delta P$). However, the over-lapped valve is too widely used to be lightly passed over and a basis for analysis is suggested, although its general application is as yet more speculative than is respectable in a data sheet. This basis is given in the diagram overleaf. The flow curve shown there is that for a nearly ideal orifice and it is to be expected that all valves designed to be 'linear' in the sense of these notes will approach that curve more or less closely, subject to some scaling factors. In individual cases these can be checked only by experiment. The factor k is fairly readily predictable but it is unfortunate that nothing very definite is known of the relation between Q_L and c in practice. The curve shows the typical effect of combined radial clearance and varying discharge coefficient. It may not be necessary to give the warning that flow measurements at the levels necessary for constructing leakage curves are very susceptible to silting, unless exceptional measures are taken. Any curve which purports to show a flow falling linearly to zero should be examined very sceptically since silting is particularly liable to produce this effect.

Heavily over-lapped valves

Two distinct classes of over-lap may

DATA SHEET—7

The diagram shows the flow curve for one port of a [illegible] in. diameter spool valve*. The orifice is fully annular with no peripheral masking or restriction. Because of this the flow can be treated as two-dimensional for port openings small compared with the spool diameter.

Beyond the point P all measured points (Q, h) fall within the lines $Q=(1\pm0{\cdot}01)kh$ up to 100 cm³/sec. Thus the valve is substantially linear. As far as R the flow is $\propto \Delta P^{\frac{1}{2}}$ for $\Delta P >$ 250 lb/in² or less, and viscosities below — cS. In this example the radius of (bluntness of) the metering edges is thought to be negligible in comparison with the clearance c.

If C_q were constant, $=C_q'$, down to $h=0$, and Q_L were due solely to the clearance, the curve would be of the form LMN, and c would be 0·000 08 in. It is probable, however, that at $h=0$, $C_q>C_q'$, giving a smaller value for c. Valves of this type can be made with Q_L as little as [illegible] cm³/sec.

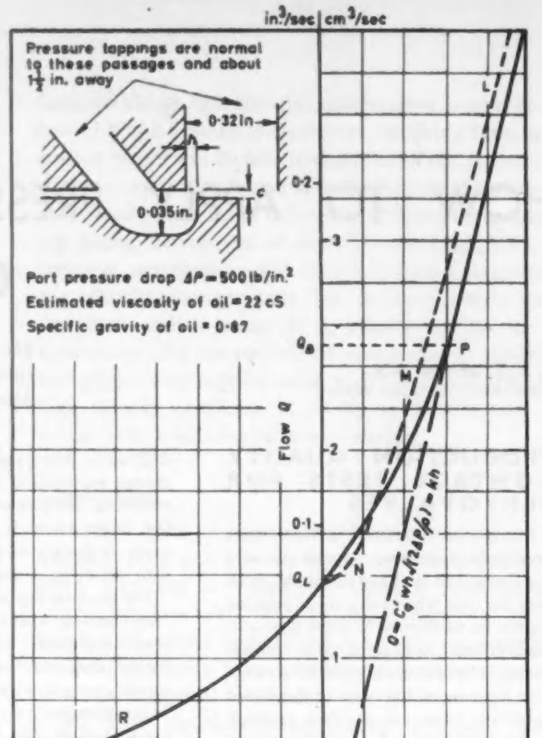
For practical purposes, h on the graph and h in the inset sketch may be regarded as identical, though it would be unwise to accept this as proven. The curves have not been checked against the theory of von Mises†, and it may be that true metering edge alignment occurs nearer to R.

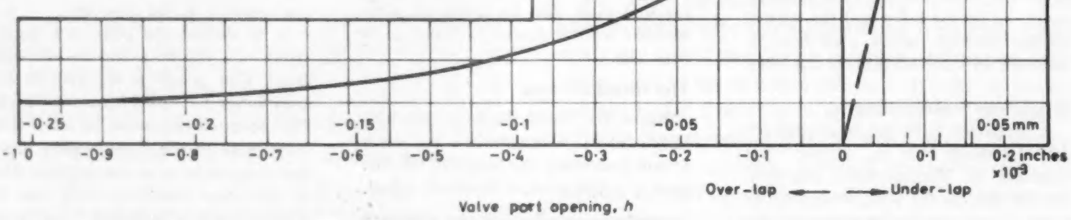
The curve PQ_LR is very accurately fitted by one quadrant of the 'sheared' cissoid

$$h=Q/k-1{\cdot}329\frac{Q_B-Q}{k}\sqrt{\left[(Q_B/Q)-1\right]}$$

neglecting imaginaries; it is expected that this form will prove appiicable to most linear ports. The constants may be adjusted to individual experimental results. The point (Q_B,h) where the curve breaks away from the linear form fairly sharply is empirical at present, but k is readily predictable. The other factor, here 1·329, governs the spread of the 'tail' in the h-direction.

* Elliott Type A204 cartridge.
† Von Mises, R.: 'Berechnung von Ausfluss und Überfallzahlen *Zeitschrift des Vereines deutscher Ingenieure*, 1917, 61, pp 47 *et seq.*





usefully be distinguished. When deliberately embodied, the over-lap is usually large, the object being to lock the output jack. The leakage flows in such a valve, when it is centred, are viscous and very small, and oil thus trapped in the oil motor gives the latter a very high stiffness when stationary. This practice dates from long before the days of extensive feedback utilization. Now, when adopted in servos, the over-lap causes instability. To counter this, dither is commonly applied with an amplitude equal to the over-lap. The aim is to round off the dead space in the flow-deflexion curve. The analysis usually used makes it appear fairly effective in doing this but if oil compressibility in the jack is taken into account it looks less favourable. In many systems improvements attributed to this probably stem really from frictional effects only. The locked stiffness is impaired somewhat by the added dither. At the extremes of the dither cycle the stiffness is least and could be found on the basis of the diagram above Near the neutral the output pressure swings very little, owing to the compressibility delays mentioned under hysteresis testing.

Lightly over-lapped valves

The other class is of valves slightly over-lapped as a result of tolerancing policy. High-performance servovalves usually fall into this category if over-lapped at all, and the significant part of any leakage is nearly certain to be largely within the turbulent region. For with present techniques, most of the desirable qualities such as low friction, threshold and hysteresis, fidelity of response, overall linearity, are all adversely affected by designing for low internal quiescent leakage. This applies not only to the more obvious case of valves with a flapper stage but to nearly all types of valve. And the higher the quiescent leakage the more likely is the flow to be turbulent at small over-laps. Performance at these seemingly insignificant flow levels has for some time now been a limiting factor in the development of faster-response hydraulic servos.

If a check shows that a curve such as that above is applicable, the (p, q, γ)-plot becomes predictable. The process of deriving it graphically is a lengthy one. Since we are usually interested in the pressure slope when the non-dimensional pressure p is less than say $\pm$ 1/3, and the lines of constant Q are fairly straight in this range, even for over-lapped valves, an algebraic derivation is more appropriate. An example is given for a three-way valve.

Example

Assume that the flow is everywhere $\propto (\Delta P)^{\frac{1}{2}}$ and that two calibration curves are available:

$(Q_i)_{cal} = C_qWf_1(X)\sqrt{(P_s/\varrho)}$ $(\Delta P = P_s/2)$

$(Q_o)_{cal} = C_qWf_2(X)\sqrt{(P_s/\varrho)}$

[The fact that at low pressure drops the flow is not $\propto (\Delta P)^{\frac{1}{2}}$ is immaterial in high pressure servos, for such drops occur only when $|p|$ is large.]

Write Σ for $C_qW\sqrt{(P_s/\varrho)}[f_1(X)+f_2(X)]$ and Δ for $C_qW\sqrt{(P_s/\varrho)}[f_1(X)-f_2(X)]$. Then the motor flow Q_m is given by $Q_m = Q_i - Q_o$

$$=C_qW\left\{f_1(X)\sqrt{[2(P_s-P)/\varrho]}-f_2(X)\sqrt{(2P/\varrho)}\right\}$$

Since $p = (2P - P_s)/P_s$

$$\frac{Q_m}{C_qW\sqrt{(P_s/\varrho)}}=f_1(X)\sqrt{(1-p)}-f_2(X)\sqrt{(1+p)}$$

For small p

r.h.s. $= f_1(X)(1-\tfrac{1}{2}p) - f_2(X)(1+\tfrac{1}{2}p)$

Therefore

$Q_m = \Delta - \tfrac{1}{2}p\Sigma$

and $p = 2[\Delta - Q_m]/\Sigma$

Hence

$$\left(\frac{\partial p}{\partial X}\right)_{qm}=\frac{2}{\Sigma}\left(\frac{d\Delta}{dX}-\tfrac{1}{2}p\frac{d\Sigma}{dX}\right)$$

$\frac{d\Delta}{dX}$ and $\frac{d\Sigma}{dX}$ are easily obtained from the calibration curve.

In particular, when $p = 0$,

$$\left(\frac{\partial p}{\partial X}\right)_{qm}=\frac{2}{\Sigma}\cdot\frac{d\Delta}{dX}$$

If $S_o = dQ_m/dX$ when $Q_m = 0$, $p = 0$ and $\Delta P = P_s/2$ (as for the calibration curves),

$$S_o=\frac{d\Delta}{dX}$$

Therefore when $p = 0$ and $q_m = 0$

$$\left(\frac{\partial p}{\partial X}\right)_{qm}=\frac{2}{\Sigma}\cdot S_o \text{ and } \left(\frac{\partial p}{\partial \gamma}\right)_{qm}=\frac{2S_oX_{max}}{\Sigma}$$

If the valve were zero-lapped the $\partial p/\partial X$ would be $S_o/Q\bar{L}$. (Q_L is the mean crossover leakage in this instance.)

Hydrogen ion concentration governs reaction rates in many chemical processes

pH - *and ways of measuring it*

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TO APPRECIATE THE NATURE OF THE pH SCALE, WE SHALL first consider briefly ionic solutions. Nearly all inorganic substances and some organic compounds are electrically conducting in aqueous solution. The first satisfactory explanation of this phenomenon was proposed by Arrhenius(*1*) in 1887, who adopted the idea that the conductivity of aqueous solutions was due to the dissociation of a substance into electrically charged free ions when dissolved in water. Since the solution is electrically neutral there must be positive and negative ions in equal proportions. Thus sodium chloride in solution dissociates according to the following equation:

$$NaCl \rightleftharpoons Na^+ + Cl^-$$

This equation does not signify a reaction in one direction but represents an equilibrium state where ions are constantly being formed and are recombining at the same rate. As a rule, metallic ions are positively charged and acidic ions are negatively charged. Substances which give electrically conducting solutions are known as *electrolytes* and those which do not as *non-electrolytes*.

Strong and weak electrolytes

We now know that this theory of Arrhenius is substantially correct. It is customary however to divide electrolytes into two classes: strong and weak electrolytes. These terms are indicative of the extent to which an electrolyte will dissociate in solution. Strong electrolytes such as the salts of acids and alkalis dissociate to the extent of about 80 - 90%; weak electrolytes, such as organic acids, give only about 1 - 3% ionization. The degree of ionic dissociation can be determined by measuring the conductivity of solutions of known concentrations.

In pure water most molecules are present as undissociated H_2O; nevertheless water does undergo ionic dissociation to a very small extent, giving hydrogen ions (H^+) and hydroxyl ions (OH^-). Water at 25°C contains 10^{-7} gramme-equivalents of H^+ ions and 10^{-7} gramme-equivalents of OH^- ions per litre. (NB. The concentration of ions is usually measured in gramme-equivalents, i.e. the weight, in grammes, of a substance which will react with or displace one gramme of hydrogen. Solutions described as 'normal' contain one gramme-equivalent of a substance per litre of solution.) The addition of an electrolyte to water will change the concentrations of H^+ or OH^- ions only if the substance itself produces them, or produces other ions which will react with them. Thus salts formed from strong acids and strong alkalis do not alter these concentrations; adding sodium chloride to water produces no change in the degree of ionization of the water itself. If, however, one adds an acid to pure water then the concentration of H^+ ions is markedly increased, since acids ionize thus:

$HX \rightleftharpoons H^+ + X^-$. (X denotes the acid radical.)

Similarly, alkalis in solution dissociate to give high concentrations of OH^- ions:

$MOH \rightleftharpoons M^+ + OH^-$. (M denotes the alkali radical.)

The dissociation constant

The product of the concentrations of H^+ ions and OH^- ions is constant in water at a given temperature and is known as the *dissociation constant*. At 25° C this con-

stant, K_w, is $10^{-7} \times 10^{-7} = 10^{-14}$. This value holds for any aqueous solution (except for very concentrated solutions), and it therefore follows that by increasing the H^+ ion concentration one decreases the OH^- ion concentration, and vice versa. If an acid is added to an alkaline solution, the high concentration of H^+ ions resulting from the ionization of the acid is reduced to a value such that K_w is still equal to 10^{-14}. This is accomplished by the combination of large quantities of H^+ ions and OH^- ions to form unionized H_2O. If the concentrations of acid and alkali are exactly equivalent the resulting mixture will be neutral. If this is not so, the solution will be acidic or alkaline depending upon whether H^+ ions or OH^- ions are present in excess.

As a matter of convenience, the hydrogen ion concentration of a solution is expressed by means of the 'pH scale', by using logarithms to the base 10. If the H^+ ion concentration is X gramme-equivalents per litre, then the pH value $= \log_{10}(1/X)$. In pure water and in neutral solutions the pH value is 7, since it is equal to $\log_{10}(1/10^{-7})$ or $\log_{10} 10^7$. It follows that in acid solutions the pH value is always less than 7 since the H^+ ion concentration is greater than 10^{-7}. Similarly in alkaline solutions the pH value is always greater than 7. Thus the whole range of reaction, in solutions, from acid to alkaline can be given in terms of pH values from 0 to 14.

In a normal acid solution (containing 1 gramme-equivalent per litre) the pH value would be $\log_{10} 1/10^0 = 0$ if all the acid were completely ionized. In practice the ionization is not quite 100%, and the pH value is slightly greater than 0. In a 0·1 normal solution of acid the pH value is approximately $\log_{10}(1/10^{-1}) = 1$.

The use of buffer solutions

In comparing the pH values of solutions of unknown concentrations, *buffer solutions* are used. These are aqueous solutions made from pure chemicals in such concentrations that exact pH values are obtained. The chemicals are chosen so that contamination by acids or alkalis produces little or no change in pH value. The name 'buffer' is adopted because of this resistance to changes in pH value.

The composition of the commoner buffer solutions can be found in any standard textbook on chemistry. Industrial firms concerned with pH measurement usually supply ready-made tablets which produce buffer solutions of a specific pH value when dissolved in a given volume of water. Potassium acid phthalate is used for most acid buffers and borax for alkaline buffers. These buffer solutions are of great importance in standardizing pH measuring instruments.

Electrical potential and pH value

The H^+ ions in aqueous solutions carry a positive charge; the presence of charged ions produces an electric potential in a solution which is proportional to the concentration and therefore to the pH value. Measurement of this potential will therefore provide a means of determining the pH value related to it.

Electrodes for pH measurement

In order to measure the potentials developed in solutions, one must set up a simple cell with two electrodes and the solution as the electrolyte between them. One electrode (called the *reference electrode*) has a constant e.m.f.; the e.m.f. of the other electrode (the measuring electrode) varies with the pH value of the solution. Thus by applying standard electrical and electronic techniques one can measure the e.m.f. of the cell and thus the pH value of the solution directly.

Many types of measuring electrode for pH determination have been devised. One of these uses hydrogen gas passing over a platinum surface and is called the 'hydrogen electrode'. The relation between pH value and e.m.f. can be derived for a cell comprising a hydrogen electrode, a reference electrode of known e.m.f. and a solution of unknown pH value. This value is given by the equation

$$\mathrm{pH} = \frac{(E - E_0)F}{2{\cdot}303\,RT}$$

where

E = e.m.f. of the cell;
E_0 = e.m.f. of the reference electrode;
R = gas constant;
T = absolute temperature; and
F = the value of the *Faraday*, the quantity of electricity (96,000 coulombs) arising from a chemical change of 1 gramme-equivalent.

The pH values of buffer solutions are usually checked from this equation, by using a hydrogen electrode and a calomel reference electrode at a given temperature.

For industrial purposes it is obviously essential to have robust measuring electrodes, stable at different pH values and able to withstand temperature changes without undue variation in response. Of all the types available today, probably the most valuable is the glass electrode. There are, however, four types of measuring electrode in common use; these are:

1 The hydrogen electrode
2 The quinhydrone electrode
3 The antimony electrode
4 The glass electrode.

Of these, only the last three are used in industrial plant: the hydrogen electrode is used for laboratory work and for standardization purposes. It would be inappropriate here to give very detailed descriptions of the construction and performance of each type of electrode, but a general indication as to the chief properties and applications is useful.

The hydrogen electrode

This is used as the ultimate standard in pH determinations and is the basis of calibration for electrometric and colorimetric systems over the whole pH range 0 to 14. It cannot be used in the presence of air or oxidizing agents or with metals below hydrogen in the electropotential series. Nevertheless when used within its limitations it gives very accurate results to within 0·01 pH units.

The quinhydrone electrode

This uses the oxidation-reduction reaction between quinone and hydroquinone, in the presence of platinum, to give a definite potential which is affected by the pH value of a solution. It is simple to use but is limited to pH values between 0 and 8·5. The accuracy of measurement within this range is good, being capable of reproduction to $\pm$ 0·01 pH units. It has severe limitations for continuous measurement since it contaminates the solution under test and is subject to large errors in strongly oxidizing and reducing solutions.

The antimony electrode

The construction of this electrode is simple; it consists of a piece of pure antimony moulded into a hard rubber tube, dipping into the test solution. The e.m.f. is developed owing to an oxide coating on the electrode which is in equilibrium with OH^- ions in the solution. The OH^- ions are, in turn, in equilibrium with the H^+ ions; the electrode gives an accurate response to pH changes in the range 2 – 8 and an approximate response from 8 to 11. Because of its robust construction, it has a wide application and can be used for pH measurement of viscous liquids, sludges and clays. It is not reliable in the presence of chlorine or metal ions electropositive to antimony, and gives errors in solutions containing strong oxidizing or reducing reagents. Where applicable, however, it is well suited to industrial recording and pH control.

The glass electrode

If two solutions of different pH values are separated by a thin glass membrane of reasonably low electrical resistance, a potential difference is produced across the membrane. This potential difference varies with the concentrations of the two solutions, but if the pH value on one side is kept constant, the unknown pH value can be derived from the measured potential. This then is the basic principle of the glass electrode; essentially it consists of a glass tube having a thin bulb of a special glass at one end. The bulb contains a buffer solution of known pH value and an inner electrode of platinum, or a silver/silver-chloride electrode. The inner electrode is an internal reference electrode and is connected to the measuring device. Fig. 1 is a diagram of a typical glass electrode.

The glass electrode is normally used in conjunction with a calomel reference electrode to complete the cell. It is probably the most widely used measuring electrode in industry, being stable in most solutions and capable of measuring pH values between 0 and 12 over wide temperature ranges. Since glass is chemically inert to most solutions, a great deal of work has been carried out in recent years to improve the performance of glass electrodes. The main effort has been concentrated on the production of special glasses for pH measurements in the range 10 – 14 at temperatures in the region of 100 deg C. One manufacturer claims a useful life of 12 months for a special electrode working at 100 deg. C. Since some glass electrodes are subject to a constant drift in reading, periodic checks are made with another electrode.

Some modern glass electrodes have been developed which can measure the pH value accurately at high pressures; others are specifically designed for use in flowing liquids. A typical 'flow electrode' is shown in Fig. 2.

This type is intended for installation in pipelines. The casing can be made in cast iron, Pyrex glass, stainless steel, rubber or lead, depending upon the specific requirements.

Reference electrodes

In addition to the measuring electrodes already described, the cell is completed with another electrode for reference purposes. These reference electrodes (sometimes known as 'half-cells') develop a stable e.m.f. in solutions of different pH values, so that the e.m.f. of the completed cell is solely dependent on the potential of the measuring electrode, and therefore on the pH value of the solution under test.

Fig. 1 A typical glass electrode

Courtesy of Electronic Instruments Ltd

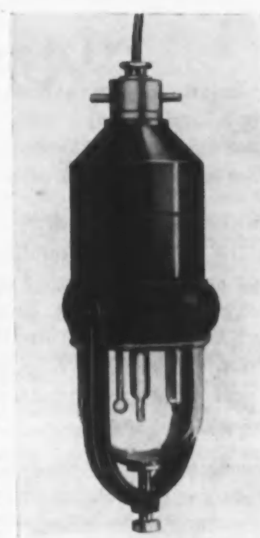

Fig. 2 Flow-type electrode

Although various types of standard half-cells have been developed, by far the most commonly used is the *calomel electrode*. This consists of mercury and mercurous chloride (calomel) in contact with a potassium chloride solution of specific concentration. The potential developed by the electrode depends upon the concentration of potassium chloride used. Most calomel electrodes are made up using a saturated solution with excess of the solid present. Such an electrode gives an e.m.f. of 0·3358 volt at 25 deg C when measured against a hydrogen electrode. This e.m.f. remains constant at different pH values of the test solution.

The reference electrode is coupled to the solution by means of a 'salt-bridge', which is usually part of the

electrode construction. In the calomel electrode the 'salt-bridge' consists of a potassium chloride solution surrounding an inner platinum wire which in turn dips into the mercury-calomel. Potassium chloride is allowed

Courtesy of Electronic Instruments Ltd

Fig. 3 A direct-reading pH meter

to seep through to the outside of the electrode, maintaining a liquid junction with the solution under test. The small amount of chloride diffusing into the test solution does not alter the pH value.

Industrial pH meters

The ability of a solution to enter into a chemical reaction is related, among other things, to the concentration of H^+ ions present. This concentration also influences such factors as ease of filtration, sedimentation, corrosive action and stability. Clearly therefore the measurement of pH value is of prime importance to the chemical engineer.

Potentiometer measurements

The e.m.f. developed by the pH electrode systems can be measured conveniently by means of a potentiometer circuit. Meters for measuring pH values are thus essentially potentiometric instruments, some using a null deflexion method and others being direct reading in either pH units or millivolts. Standardization is carried out with buffer solutions of known and accurate pH values.

With low-resistance electrodes (such as the antimony electrode) a self-balancing potentiometer can be directly connected to the cell. The stability of this system however can be improved by using an intermediate amplifier. When a glass electrode is used, the high resistance of the glass membrane (about 10^8 ohms) does not allow the use of a simple galvanometer in the circuit; an electrometer valve system then becomes necessary. The voltage to be measured is applied to the grid of an electrometer valve in the first stage of an amplifier and the amplifier output is used to obtain either a direct reading or a null reading in a galvanometer circuit. At 25 deg C, 1 pH unit is equivalent to about 60 mV.

Since the potential developed in a solution varies with temperature, all modern pH meters incorporate a temperature compensating mechanism; pH determinations can thus be carried out at varying temperatures even though the instrument has been standardized at room temperature.

Types of meter and their accuracy

Most of the recent developments in pH meter design have been directed towards producing a suitable and stable form of direct-coupled amplifier. There are five or six manufacturers in the United Kingdom who make pH meters for laboratory use; most of these instruments have been adapted, with a few modifications, for industrial purposes. A typical direct-reading pH meter for laboratory use is shown in Fig. 3. For use in process control, pH meters can be divided into two distinct types:

1 Those which amplify the e.m.f. of the cell and use the output to operate a recorder or controller
2 Those which compare the e.m.f. of the cell with an accurate standard e.m.f.

The pH meter of today is essentially a sensitive valve voltmeter, the particular circuit used being dependent upon the manufacturer and the purpose for which the instrument is required. Some meters on the market are capable of measuring pH value to an accuracy of $\pm 0{\cdot}001$ unit (or e.m.f. to $0{\cdot}1$ mV) although these are largely used for research purposes. For industrial work it is usually satisfactory if the pH value is determined to an accuracy of $\pm 0{\cdot}1$ unit. The important factor here however is that the instrument must be stable enough for the accuracy to be maintained over long periods.

Output

The amplified output from an industrial pH meter can be fed to the conventional strip-chart recorders or to controllers of the self-balancing potentiometer type. Multiple readings from several measuring electrodes can be simultaneously recorded on the same chart or the pH value can be recorded together with other variables in the system.

From the above, it is apparent that the electronic pH meter is well adapted for incorporation into an automatic control system for batch or continuous processes. Sample composition is not normally affected by the measurement although this depends largely on the appropriate measuring electrode being chosen. Zero drift of the meter however becomes important and it should be checked at regular intervals; some meters are provided with a means of checking the zero without the need for buffer calibration.

Conclusion

This article is intended only as a brief survey of the broad field of pH measurement. For further details of the use of pH meters in industrial control systems, those interested should consult the very valuable series of articles by D. C. Nutting (*2*).

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CONTROL IN ACTION

£10 million extension to Esso's Fawley refinery leans heavily on instruments to supply petro-chemicals to Monsanto, Gemec and ISR

Instrumentation at Fawley

THE OIL REFINING INDUSTRY HAS ALWAYS been in the forefront of the users of instrumentation and control, flow products lending themselves well to the use of modern process control techniques. An oil refinery handles valuable products in quantity and is much concerned with quality control.

This heavy reliance on instrumentation is immediately apparent on visiting the new petroleum chemicals plant of the Esso refinery at Fawley. The refinery has been in operation since 1951 (although a small refinery has been operating there since 1921), and has been expanding ever since. The chemicals plant, which was officially opened by the Minister of Power, Lord Mills, last month, is the latest phase in this expansion. Some £M68 has been spent on the refinery and the chemicals plant accounted for £M10 of this, although chemicals will account for but 1% of the total crude feed.

Starting from a light petroleum fraction feedstock and C_3/C_4 gases, the new plant at present will produce two chemical raw materials, ethylene and butadiene. About 40,000 tons/year of ethylene will be piped as a gas to the two nearby factories of Monsanto Chemicals Ltd (11,000 tons) and Gemec Ltd, a Union Carbide subsidiary (18,000 tons). Some 3000 to 5000 tons/year of liquid ethylene may also be shipped in road tankers. Butadiene will be produced at a rate of 42,000 tons/year and piped as a liquid to the nearby factory of the International Synthetic Rubber Co Ltd—a consortium of the leading firms in the rubber industry—for manufacture into butadiene-styrene rubber.

Ethylene for Monsanto and Gemec

Briefly, ethylene is produced by cracking light petroleum fractions at high temperature in the presence of steam. The light naphtha feed is passed through a fractionating tower, to remove pentanes etc and fed to the steam cracker furnaces. The charge is mixed with steam and heated to about 1000 deg F, oil-quenched and compressed. The light ends from this process are washed and passed to the ethylene recovery unit. The heavy ends are fed to a debutanizer whose 'bottoms' provide a naphtha stream which is clay-treated for gasoline blending. The debutanizer overhead product is separated into C_3's (propylene) and eventually converted into high-octane fuel, and a C_4 stream which goes to the butadiene extraction plant.

In the ethylene recovery unit, low temperature fractionation separates the ethylene from the lighter fractions. Acetylene is removed by hydrogenation, and further processing removes methane and hydrogen. The feed is passed to an 80-tray ethylene-ethane splitter tower, the 'bottoms' being ethane and going to fuel gas, and the overhead product being high purity ethylene.

Butadiene for ISR's synthetic rubber

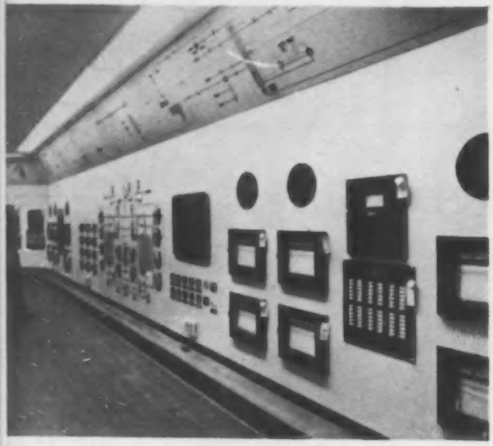
The main feed is a C_3C_4 stream from the catalytic cracker although C_4 from the ethylene steam cracker is also fed in at a later stage. The C_3/C_4 feed passes through a de-propanizer and de-isobutanizer, to give C_4 which is fed to an isobutylene extraction unit. The product, which then consists principally of butenes, is passed through a dehydrogenation process to give a dilute butadiene stream. This, together with the butadiene stream from the steam cracker, is subjected to butadiene extraction, and the product re-run in a fractionating tower, condensed overhead and stored in spheres as 98·5% pure butadiene liquid.

The steam cracker and butadiene control rooms

There are two main control rooms concerned with the chemical plant, the smaller covers the ethylene-producing steam cracker process and the larger (60 ft by 40 ft) the butadiene dehydrogenation, extraction, refrigeration and recovery plants and ancillary processes. The two control rooms are equipped in similar fashion; and indeed there are no drastic departures from earlier designs installed at Fawley.

Pneumatic transmission and control are employed, miniature indicators and strip chart recorders being mounted in conventional fashion four tiers high. Temperature multipoint recorders and indicators are used, these having 12 in. strip charts and full-size electronic panel-mounted indicators. Temperature controllers for the lower ranges are 'filled system' pneumatic transmitters connected to miniature panel-mounted recorders. The higher temperature operating equipment uses thermocouple detectors. The controllers are of the stack type and are wall-mounted behind the control panel for ease of maintenance.

The introduction of miniature recorders and indicators has so reduced the panel area required that there is insufficient room for the usual type of



The butadiene control room. Note mimic flow diagrams as frieze to the panel

light alarm. Cabinet-type light alarms by Panellit have been used to overcome this congestion.

The centre-piece of the larger control room is a graphic section and valve sequential operator of the reactor section of the butene dehydrogenation process. Valve positions are indicated on the graphic flow panel. Mimic flow diagrams, suitably colour coded and fitted as a frieze to the panel (see illustration), act as an index to the instruments mounted below. The code is as follows: flow, red square; level, green rectangle; temperature, blue diamond; pressure, yellow circle.

The application of special instruments has been viewed with reserve, and in consequence few have been installed as yet. Three of the more unusual forms of instrumentation are, however, in use. A CO_2 analyser by Grubb Parsons, monitors carbon burn-off, the gas being detected by an infra-red method. A dew-point meter is fitted to the gas drying section, to indicate moisture break-through prior to putting a column on regeneration. An explosivity meter, by Mine Safety Appliances, has been installed because ethylene road-loading facilities are provided and the atmosphere must, therefore, be monitored for ethylene content. Six strategic points are monitored, and alarms and cut-off devices operate when a preset concentration is exceeded. A fraction of the sample air is passed over a heated detector filament which forms part of an electrical bridge. The detector is fitted in a combustion chamber and any inflammable gases in the sample are burned by the filament.

Investigations are proceeding into the analysis of butadiene purity—probably by refractometry—and also into acetylene and carbon monoxide in ethylene by vapour phase chromatography.

Among the firms concerned with the instrumentation of the chemicals project were Crosby Valve, Fisher Governor, GEC, Honeywell-Brown, Negretti & Zambra, Sunvic Controls and Taylor Controls.

CONTROL IN ACTION

Unmanned Canberra as target

THE CANBERRA IS A WELL-KNOWN aircraft which has found world-wide employment in a number of roles. One of its latest uses has been as a target, and for this some surplus aircraft have been modified for unmanned operation. The modified version, the U10, has been developed by Short Brothers & Harland Ltd and will be used in guided weapons trials. The advantages of the U10 over existing targets include its relatively long endurance and ability to achieve heights in excess of 55,000 ft.

The Canberra can takeoff and land automatically and in between can be placed by push-button control into one of six basic 'fixed' attitudes. Each of these attitudes corresponds to an important flight condition. For a typical flight these attitudes might follow one another in this way: climb, slow level, fast level, maximum level, fast glide and land glide (approach). These basic attitudes can be modified by a pitch 'beep' control. For example the pitch-up 'beep' signal causes the aircraft to pitch nose up at a steady rate as long as the control is depressed. When the 'beep' signal stops the new attitude is held until a further signal is received.

The principle used in automatic landing is different from that recently demonstrated by the Blind Landing Experimental Unit, which uses magnetic leader cables, or the Bell lock-on radar system. The Canberra system, developed by RAE Farnborough, involves three skilled operators on the ground, the azimuth sight controller, the pitch sight controller and their overseer, the master controller. The master controller can use radar for 'out of sight' operation, but for landing he needs these two assistants who visually sight on the aircraft. All must work in clear visibility; but this definite limitation may not be so important when applied to aircraft which will spend most of their time in the clear sunshine of the Australian missile grounds.

Radio control from the ground

Information is passed by radio link from the master controller to the aircraft by using a series of tone pairs. As each tone pair is received in the aircraft it is routed by tuned filters to the appropriate relays which then initiate the required operation. This can be clearly seen in the drawing.

A destroy signal can be picked up by an additional receiver which is supplied from a separate battery. This signal is used to detonate an explosive charge which severs the tail unit. To provide performance and navigational information for the master controller a 24-channel telemetry transmitter and a missile tracking system are provided in the aircraft.

The autopilot and steady flight

An Elliott type B autopilot, originally designed at RAE, maintains the aircraft in steady flight whilst in a fixed attitude. It was developed as a 3-axis system, but the rudder is now controlled by the yaw integrating rate gyro only during the period of landing and take-off. At all other times the rudder is uncontrolled and takes up its neutral position.

There are four gyroscopes, each working on the electric spring principle, and these are shown in the drawing. The yaw integrating rate gyro is mounted rigidly to the aircraft. The pitch rate gyro is fitted to a platform which may be set to any demanded pitch angle by the motor. The roll unit consists of a similar platform on which is carried a horizon gyro unit, a rate gyro and turns computer. It has been found that the most satisfactory control in roll and yaw for straight flight is a form of aileron steering. This applies aileron proportional to functions of yaw rate, yaw displacement, roll rate and roll displacement. During turns the aileron signal is modified by an additional trim term from a height lock signal.

Modifying the basic pitch attitude

It has already been mentioned that the basic pitch attitudes can be modified by 'beeping', and the changes caused by this or another demand, take place at a rate of 4°/sec. The demand for a change causes the pitch platform to be rotated to a selected position by the motor, resulting in 1) a rate gyro output during the rotation, which is used to modify the pitch attitude; and 2) generation of a

demanded attitude datum by a pick-off, which is compared with the horizon gyro unit and used to maintain the aircraft in its new attitude. A capsule-operated height lock is also used in level flight as a monitoring signal to prevent slight attitude drift, particularly in turns.

Another input to the pitch circuit comes from the airspeed error. In order to obtain efficient aircraft performance the 'full' and 'flight idling' throttle settings are used in conjunction with the climb and fast glide attitudes. Consequently the airspeed errors fed to the throttles are in these attitudes routed into the pitch channel. Thus too low an observed airspeed will demand a nose-down change and vice versa. This form of airspeed control only becomes effective once the aircraft attains the correct speed for the chosen attitude.

Banking the aircraft

The normal fixed attitude is that of straight flight, but the aircraft can be made to bank to one side or the other by port or starboard 'beep' signals. A 'beep' signal rotates the roll platform through an angle equal and opposite to the demanded bank angle for the turn. This rotation has two effects, 1) the yaw unit is cut off from the roll amplifier, so the aileron demand becomes a function of roll rate and displacement only; and 2) the turns computer is brought into use. This computer finds the pitch and roll rates for a steady co-ordinated turn; and to do this it is provided with the true airspeed, and the pitch and roll datums. Voltages proportional to these values are fed to the turns rate compensation coil of each rate gyro to ensure zero output for a correct turn.

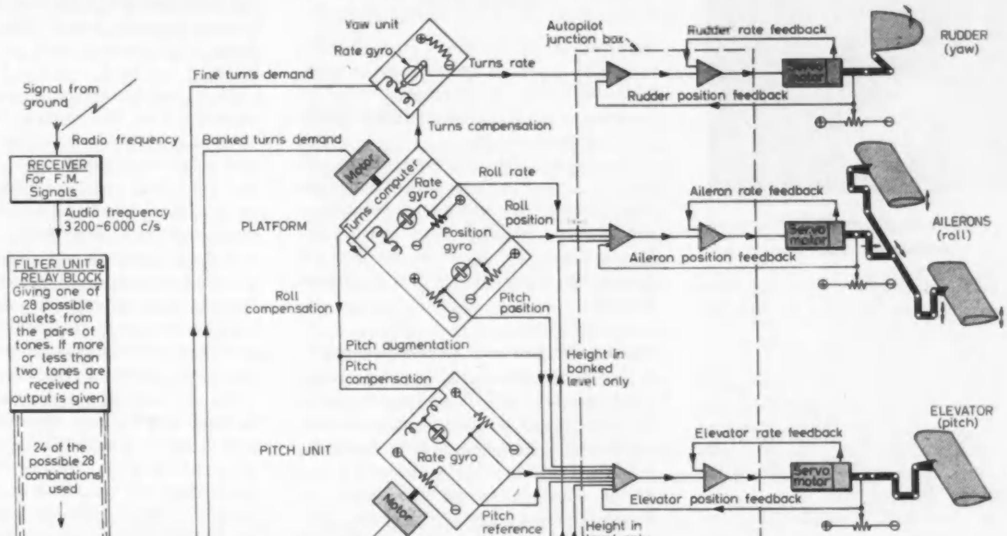
The mixing of the signals in the different channels is carried out by magnetic amplifiers, each of which has four input windings. The output of each magnetic amplifier is connected differentially to a high-speed relay, which produces a signal representing the difference between the input signal and the position-feedback. The relay actuates one of two Elliott magnetic clutches, which are driven in opposite directions by a shunt-wound motor. The output shaft rotates in a direction determined by which clutch is actuated. The velocity-feedback from a d.c. generator is fed into the relay coil, and is adjusted by an attenuator until the servo is correctly damped. With correct damping the output shaft will follow the input signal in small, discrete steps, without overshoot. The maximum output torque is 70 lb/ft, with a backlash of less than $\frac{1}{4}°$ at the output shaft.

Engine and landing controls

An Ultra Electric airspeed and throttle control system provides airspeed and altitude control in response to selected fixed attitudes, or 'beeping'.

When the fixed attitude land glide is selected the undercarriage is automatically lowered. On touchdown, the braking parachute is streamed, and the wheel brakes are differentially controlled by signals from the rudder channel. During take-off the undercarriage will be withdrawn when the speed off the ground exceeds 130 knots.

One question springs to mind when considering the use of this comparatively old aircraft and that is how long it will be before a supersonic target is produced. Modern supersonic planes are so rare and expensive that it seems doubtful whether they will ever be converted to targets as these Canberras have been.



Though this diagram of the Canberra U10 control system appears complex it comprises a number of simple closed loops. The autopilot, with its associated loops, maintains the aircraft in steady flight in any one of a number of fixed attitudes, such as a climb or a fast level flight. A change in this attitude can be made by a ground radio signal

Taken from RAeS lecture 'Drone Aircraft' by Conway

NEWS ROUND-UP

from the world of control

Hydraulics firms merge

The Dowty Group's acquisition of Rotol, the variable pitch propeller company, is of more than passing interest to control engineers despite the fact that it would appear to be just another example of integration in the aircraft industry. Basically both firms are aircraft equipment manufacturers but they have unrivalled experience in the field of hydraulic control and there are signs that they are now entering the industrial control market.

Rotol's SIR JOHN EVETTS
A change of pitch

SIR GEORGE DOWTY
Greater thrust

Rotol was formed in 1937 by Rolls-Royce and Bristol Aeroplane to design and manufacture variable pitch airscrews, and they are still the largest British manufacturer of such products. They also did a great deal of work on controllable pitch marine screw propellers, although they are no longer in that field. Undercarriages and other hydraulically operated aircraft components are other Rotol and British Messier (an associated company) products, and we understand Rotol to be very interested in the potentialities of electro-hydraulic servo systems.

The Dowty Group have a similar background as suppliers to the aircraft industry. They are probably best known as designers and manufacturers of hydraulic retractable undercarriages, products which they pioneered. Nowadays, however, they manufacture a wide range of products including, for example, nucleonic instruments. Among their hydraulic devices are hydraulic components for missiles, pumps for aircraft services, servo valves, hydrostatic transmission for industrial and agricultural purposes, industrial pumps, control valves, rams and couplings, seals of various types, hydraulic buffers and pit props, a hydraulic-powered roof support system, and heavy-duty hydraulic pumps.

It can be seen, therefore, that both concerns have extensive experience of hydraulics and many years of operational experience behind them. We shall be surprised if the Dowty-Rotol tie up does not lead to interesting developments in hydraulic control.

Curtiss-Wright seek British licences

That this move by aircraft equipment manufacturers into the more general industrial field is not peculiar to this country, is borne out by the fact that the propeller Division of the American Curtiss-Wright Corp would like to manufacture British products under licence in the USA. According to the Export Services Branch of the Board of Trade, Curtiss-Wright say 'The product or production line we seek should be a fairly complex, mechanical assembly. The inclusion of electric, electronic or hydraulic elements is satisfactory, but emphasis will be placed on products having a predominantly mechanical character with an intermediate quantity production potential . . .' Among the products they are interested in are pumps and compressors, hydraulic valves and valve operating equipment, mechanical or hydraulic valves and transmission systems, and actuation equipment. The person to contact is B. W. Dudley, Vice President and General Manager, Curtiss-Wright Corp, Propeller Division, New Jersey, USA.

Thomas makes control live

'Just as atomic energy is displacing man's physical effort so is automation displacing man's mental effort', said Dr H. A. Thomas in his 1958-59 Faraday Lecture. This has been, or will be, given in 13 towns including London (see *Looking Ahead*), where it will be presented on 26th January. The Lecture, although intended for laymen, has aroused a great deal of interest among engineers—indeed, all tickets for the London presentation have already been taken up. Could not Londoners be given another opportunity to see this show later this year?

Dr Thomas, who is Manager of Unilever's Instrumentation and Control Section, gives his audience two hours of real entertainment—and instruction. Thomas begins by outlining man's increasing use of tools to help him in his work. As machines became faster and more complex, the limitations of man's senses became more important. Real automation helps man's senses and particularly his brain.

Next he considers process control, showing how the introduction of continuous processes in the oil industry makes full instrumentation essential. A diagrammatic working model of oil flow in and out of a tank illustrates level control under steady and fluctuating conditions.

From process control to position control in manufacturing industry—and here Thomas gives examples in each of the five sections into which he divides production: making, inspecting, assembling, testing and packaging. Several colour films are shown.

But although the instruments described so far help man's senses, they do not greatly relieve man's brain. Thomas turns to an automatic weighing machine, to show true automation—in which the machine makes decisions. The equipment itself, which is for moulding dough balls, is seen on a film. The dough balls vary slightly in density but provided that the mean weight stays within acceptable limits no action is taken. If the weight shows a definite trend the machine alters the size of the mould. To illustrate this Thomas has linked two working models, one with balls running down onto weight platforms with indicating dials and lamps showing whether the weight of each ball is correct and general trends in their weights, and a second showing how variation in density is automatically controlled. This second model is an ingenious affair in which tennis balls are catapulted across the front of the stage onto an inclined tray. Variation in density of the dough is simulated by

altering the angle of projection of the tennis balls and the correcting change in mould volume by moving the catapult platform across the stage. The equipment gives remarkable consistency in the balls' flight.

This example leads naturally on to computers. The lecturer skilfully puts over binary arithmetic by means of a film and himself adds binary numbers on a working model by closing knife switches. A fine model of a computer includes pillar box openings, about two feet wide, that accept and deliver paper tape on the same scale forming the input and output.

Thomas ends on a stimulating note. He appeals to British people to realize that their economic survival is linked with the adoption of the new techniques.

Kennedy, Thomas's chief assistant, at the control console during the Faraday Lecture

– DATA HANDLING –

SIT's digital-storage Symposium

Punched cards, 'Digitape'—a new recording medium, punched tape, and magnetic tape, will all receive their due at the Symposium on digital storage media which is to be held by the SIT on the 14th January, 1959. Powers-Samas' D. F. Nettell will uphold the punched card in his paper 'Some Recent Developments in Punched-card Machines'. Two classes of machine are considered, those for punching cards from instruments with digital outputs, and those for using punched cards as input to numerically-controlled machines and processes.

E. J. Petherick of Benson-Lehner (G.B.) Ltd will describe 'Digitape—a Novel low-cost Recording Medium'. He argues that two basic techniques only are extensively used for recording digital data: 'subtractive'—the punching of holes in cards or tape; 'physical change'—magnetizing surface coatings on tapes, drums, etc. Digitape is subtractive. An opaque metallic film on a transparent plastic tape is vaporized locally using current from a stylus, and photo-electric read-back is employed.

'Digital Storage on Punched Tape' by M. E. Theis of Creed & Co lives up to its title, being a description of punched paper tape, the methods of coding digital information on it, and the equipment available for handling it and using it for computer input and output. 'The Storage and Processing of Digital Data on Magnetic Tape' by D. W. Willis of Decca Radar, reviews the special features of magnetic tape and film for the processing and storage of digital data. The limitations and methods of circumventing them are discussed, examples are given and desirable features are outlined. Various tape transports and heads are described.

Four papers describing four different recording media; the discussion should be lively.

— CHEMICALS —

Salt valve control

An essential part of the plant used in the production of salt by the Middlewich Salt Co is a number of hydraulically operated valves. These are operated on a time cycle by water from a pressure vessel at 65 to 80 lb/in^2. The required pressure within the vessel is maintained automatically by two cast iron sliding-shoe pumps (main and standby) each capable of supplying 800 gal/h at 85 lb/in^2. Control takes place in the pressure lines between the vessel and three salt valves. Three solenoid-operated changeover valves, operated by time switches, are mounted on the control panel, and each changeover valve in turn admits water under pressure to the appropriate salt valve. The pressure system equipment—pumps, pressure vessel, pressure switches, automatic starter and selector switch—was supplied by Megator Pumps and Compressors.

Automatic pressure system for the hydraulic operation of valves at the Middlewich Salt Co

— ATOMIC POWER —

EMI-UKAEA data system

The problem of continuously monitoring nuclear experiments for 24 hours at a stretch and handling the immense quantity of data which results—millions of separate measurements to 0·1% accuracy, or better—has resulted in the development by EMI Electronics and the UKAEA, of a transistorized data recording and analysing system for use at AERE, Harwell. Using a limited range of plug-in transistor 'cards', the system comprises a number of magnetic tape recorders and a central high-speed analyser. The recording units take the measured quantities—e.g. neutron time-of-flight and scintillation counter identity—and convert them into binary form. The coded data are recorded in parallel form on 16 channels using 1in. tape. After a run the tapes are removed, leaving the rig free for a further run if required, and processed in the central analyser. This handles the tapes at up to 100 in/sec, reads off the digital information, and holds it in a ferrite core store. The contents of the store may, for example, be transferred on to punched tape for input to a digital computer. Punched card or graphical output are also available.

Initially the system is being applied to neutron spectrometry measurements, but it is said to be readily adaptable to any problem where data is to be recorded over a long period. The magnetic recording stage can be by-passed if the data is arriving at high rates and, after conversion into digital form, directly sorted into the analyser's store.

– IRON AND STEEL –

Controlling multi-stand mills

The automatic control of multi-stand rolling mills for the production of thin sheet steel presents some sticky problems. Towards the end of the manufacturing process, the sheet is cold-reduced to a finished gauge on

BRISTOL FASHION

Final tests being carried out on Grace, the electronic register-translator equipment at Bristol central telephone exchange—the first in the country to provide subscriber trunk dialling. The equipment is capable of completing over 6000 calls an hour (*Courtesy of GEC*)

continuous multi-stand rolling mills. In a typical five-stand mill, 0·1 in. thick strip is given five successive reductions down to 0·01 in. Large tensions between stands are necessary and, as the material increases in length during rolling, successive stands must run at ever increasing speeds. The strip may enter Stand 1 at 500 ft/min and leave Stand 5 at 5000 ft/min. A major problem is that the original hot-rolled material varies in thickness, and the cold mill must adjust this if the finished product is to be within tolerance. The problem of controlling this process automatically is, therefore, a difficult one.

A model rolling mill

In a paper read recently before the Society of Instrument Technology, 'An Experimental Approach to some Control Problems of Multi-stand Rolling Mills' by H. Gill of the British Iron and Steel Research Association, one approach to this problem is described. Bearing in mind the many variables which can affect the process (e.g. interstand tension, rolling load, gauge of feed strip and so on), BISRA constructed a model multi-stand mill and analysed its performance. It is a three-stand mill accommodating rolls 2⅝ in. diameter by 1 in. face width, and both the mechanical stiffness of the stands and the speed/torque characteristics of the driving motors can be varied. The mill is powered by seven 1/7-h.p. split-field servomotors, geared down by 400, 300, and 200 to 1 on Stands 1, 2 and 3 respectively, so that the finishing strip speed is 15 ft/min.

Speed control

Tachogenerator-feedback speed control is employed, a speed reference voltage being obtained from a speed-setting potentiometer which is connected across a master potentiometer common to all three stands. Variable speed regulation is derived from a strain-gauge torquemeter which feeds back a signal opposing the speed reference voltage. The magnitude of the motor torque speed variation ('droop') is controlled by a potentiometer from the torque meter amplifier. The model is well instrumented, roll force, torque and interstand tension being measured by resistance strain gauges.

Mr Gill feels that the use of a model for the detailed analysis of mill behaviour offers many advantages. Stand characteristics may be chosen to give the best inherent regulation and the designing of multiple closed-loop systems to control every variable is avoided.

The paper, which was well received, was followed by a lively discussion. The general concensus of opinion seemed to be that BISRA's approach is the next best thing to obtaining measurements on a full-size machine operating under normal working conditions—a difficult if not impossible task.

Another for Appleby-Frodingham

Having commissioned their new 8000 h.p. twin-motor reversing plate-finishing mill at the Appleby Steelworks, the Appleby-Frodingham Steel Co (a branch of United Steel) have awarded another important contract to AEI Heavy Plant Division at Trafford Park (i.e. Met-Vick; BTH are at Rugby).

The contract calls for the electrical main drive equipment for a new 12 ft twin-motor reversing plate roughing mill to operate in conjunction with the recently-commissioned finishing mill. It will roll slabs weighing up to 25,000 lb down to dimensions suitable for finish-rolling in the finishing mill, the two mills being situated in line to facilitate ease of transfer and to reduce handling size. The new mill will be of conventional two-high construction, having two work rolls 46 in. diameter by 12ft 6 in. long. Each roll will be driven by a 3000 h.p. (r.m.s.), 40–80 r.p.m., 1000 volt d.c. motor, and the maximum peak output from the twin-motor drive will be 18,000 h.p.

Hand-operated master controller

The mill will be controlled by means of a light, hand-operated master controller. The electrical control scheme will use amplidyne rotating amplifiers operating in conjunction with laminated yoke exciters. This gives rapid rates of response to the demands of the operator and reversal times of the order of 3 sec from top speed forward to top speed reverse. The main motor-generator set, a duplicate of that supplied for the finishing mill, will comprise four 1600 kW generators, a 6000 h.p. induction motor and a cast-iron steel flywheel weighing approximately 32 tons.

SHIPPING

Transmitting magnetic compass

An interesting development by Kelvin & Hughes (Marine) could form a basic component of that classical controller, the automatic helmsman. They have produced a transmitting magnetic compass which appears to offer a number of advantages over competing systems. The latter employ photoelectric cells, selenium cells, Wheatstone bridge devices, and gyro-magnetic methods to transmit compass information.

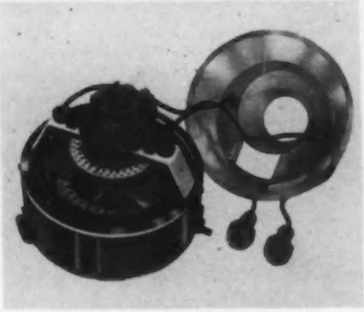
The Kelvin Hughes system is of the electromagnetic type, a detector-transmitter unit being mounted on the underside of the bowl of a standard magnetic compass. The detector coil beneath the compass bowl is energized at 200 c/s from an amplifier. The secondary winding of this coil, however, gives zero output when the coil is in line with the N–S points of the compass magnet. When the magnet moves from this position, the change in direction of the magnetic flux results in a signal being induced in the secondary winding. This signal is amplified

Appleby-Frodingham have recently commissioned this plate-finishing mill at Scunthorpe

and fed to a follow-up motor which will rotate in one direction or the other depending upon the phase of the signal. Motor speed is governed by the amplitude of the signal. The voltage rises and falls in relation to the difference in angle between the coil and magnet; when coil and magnet are in line, the motor comes to rest.

Follow-up servomotor

The detector coil is coupled via a 90 : 1 gear ratio, to a step-by-step transmitter (an Evershed & Vignoles M type) which controls the various repeaters. It is also



Underside of compass bowl, showing detector and servomotor

mechanically connected to the follow-up servomotor by a sun and planet gear system. The motor-to-transmitter ratio is 35 : 1. The servomotor is a two-phase type, the reference phase being continuously energized from a power amplifier; the control phase is energized only when compass-magnet and detector coil are out of alignment.

OIL

Autocontrolled oil wells

A $100,000-plus contract has been awarded to Texas Instruments Inc for the electrical control and automatic programming equipment for Venezuelan Sun Oil's oil-well lease processing unit on Lake Maracaibo. Unattended, completely-automated units will process test data, and punch it on tape for periodic delivery to shore for computation for accounting and reservoir analysis purposes. A 'Data-Gauge' digital code transmission system will control individual well-diverter and shut-in valves. When commissioned in mid-1959 the equipment will handle approximately 40 well completions producing about 100,000 barrels a day.

Incidentally, we understand that it is proposed to merge Metals & Controls Corp (clad-metal products, thermostatic controls, motor controls etc.) with Texas Instruments Inc.

To return to Lake Maracaibo, Nife Batteries inform us that four of their 50 volt batteries will provide auxiliary current for the semi-automatic operation of the pumping stations associated with the Compania Shell de Venezuela's major oil-pipeline project.

IN BRIEF

● **Hydraulics Division** of Fairey Aviation has manufactured more than 15,000 sets of power controls for various aircraft, and are now studying developments in the commercial field, according to the Chairman's speech at the recent AGM.

● **Largest PABX** in Britain will be installed by Automatic Telephone & Electric in Shell's South Bank building. With a switchboard of the new cordless type, the PABX will start with 4500 lines and eventually have 7000 lines. Expected to be in operation in mid 1961, the equipment will have 19 operators' positions, 179 lines to the public exchange, private lines to other Shell premises and loudspeaking telephones.

● **Standards.** Delegates from Belgium, Germany, India, USA, and USSR who were in this country to attend the Conference of the International Organization for Standardization (ISO) concerned with liquid flow measurement in open channels, were given a luncheon last month by the British Industrial Measuring and Control Apparatus Manufacturers' Association. Representatives of the British Standards Institution were present.

● **Process instrumentation** symposium held by Sunvic Controls for fellow AEI group members and others, covered automatic control and instrumentation for continuous flow production—oil, chemicals, nuclear power. Data processing and automatic computation for fully automatic plant control was emphasized.

● **Pace.** The third Pace analogue computer to be sold in Britain has been ordered from the European Division of Electronic Associates Inc by UKAEA. The other two went to AERE Harwell, and GEC Erith.

● **EMI-Cossor (Canada).** Electric and Musical Industries and A. C. Cossor are to co-operate in electronics in the Canadian market. Based on Cossor's Canadian subsidiary, Cossor (Canada) Ltd, a new company, EMI-Cossor Electronics, will be formed in which EMI will have a controlling interest.

● **Nine 'no break' generating plants** and their control gear are being supplied to the New Zealand government by Pelapone Engines Ltd, for installation at airports.

● **Cablemakers.** British Insulated Callender's Cables and Telegraph Construction and Maintenance Co are to merge, BICC intending to acquire the entire share capital of Telcon.

● **VOR for UK network.** The Ministry of Supply has ordered eleven complete v.h.f. omni-directional radio range equipments (VOR) from Marconi's Wireless Telegraph Co, on behalf of the Ministry of Transport & Civil Aviation.

● **CIBA Fellowship Trust** has been founded to improve and increase the interchange of ideas between British and European scientists. Details from the Secretary of the CIBA Fellowship Trust, CIBA (ARL) Ltd, Duxford, Cambridge.

● **Hawker Siddeley (Hamble)** a new Hawker Siddeley company, is being formed to service Petter and Armstrong Siddeley diesel engines, produce generating sets and marine engines and auxiliaries.

● **Closed-circuit television** by EMI Electronics, is being used by the NCB's Central Engineering Establishment, to enable the operator of a compression testing machine to observe pit props and chocks being submitted to loads of up to 360 tons.

● **32,000 water meters** recently ordered from George Kent Ltd by the Teheran Water Authority, bring to over £300,000 the value of Kent meters ordered by the Authority since 1956.

● **Red Duster** and **Red Shoes,** guided weapon projects mentioned in a recent RAF court martial, are better known as the Bristol Bloodhound and the English Electric Thunderbird.

● **Control valve activities** of James Gordon & Co of the Elliott-Automation Group, will be handled by a new company, James Gordon Valves Ltd, Airport Works, Rochester, under directors G. C. Fairbanks, H. Masheder, J. E. O'Breen and H. R. Walton.

● **Inertial navigation** system for the Avro Stand-off Bomb was developed by Elliott Brothers (London) Ltd in conjunction with the Ministry of Supply and RAE, Farnborough. Elliotts have formed an Inertial Navigation Division under Mr W. A. Fraser.

● **Elliott Nucleonics Ltd** is to assume responsibility for all the activities in the nuclear field of Elliott Brothers (London) Ltd.

● **I.Mech. E.** A new publication, the *Journal of Mechanical Engineering Science*, is to be published quarterly by the Institution of Mechanical Engineers.

● **New Year Honours. A. F. Burke** deputy chairman and managing director of de Havilland Aircraft—knighted.

G. W. H. Gardner director of RAE Farnborough—KBE.

P. T. Fletcher deputy managing director of the Industrial Group (Risley) UKAEA —CBE.

J. H. Reed managing director of Ericsson Telephones—CBE.

D. J. Farrar chief designer, guided weapons, of Bristol Aircraft—OBE.

Pick-off *by 'UNCONTROLLED'*

MANY people will be delighted to see that Dr G. W. H. Gardner, the Director of the RAE, was appointed a KBE in the New Year Honours. I thought that he made a good point from the Chair at the Royal Aeronautical Society meeting on 17th December, when H. G. Conway's address on 'Drone Aircraft' was under discussion. Gardner said, 'Not enough attention has been paid to simplicity by instrument engineers, and this has been accompanied by a trend to do too many things electronically, thus leading to very expensive solutions'. I gather that he has in mind particularly the use of elaborate electronic circuits for elementary computation such as squaring, when a simple mechanical device can give the answer satisfactorily if not so rapidly. Undoubtedly our present methods of training instrument and control engineers put too many electronic engineers or physicists into positions where they ought to know a good deal about mechanical, pneumatic and hydraulic components to produce economical system design.

LAST month I wrote, 'The manufacturers' association is not the sort of organization that benefits from competition.' Nor is the professional society. Surely it is high time that the BritIRE and the IEE resolved their silent conflict. The stupidity of this is underlined by the BritIRE's recent announcement that they are seeking a Royal Charter. If the Institution obtains it there will be two chartered bodies officially representing the advancement of radio and electronic engineering in this country. It may well be that there is room for two professional electrical engineering societies, but if so they should be complementary rather than competitive, as are the two corresponding American societies.

The behaviour of the Councils of the two British bodies in not publicly recognizing—even *de facto*—each other's existence is, to my mind, rather childish. But many men serve on each Council who must realize that the existing state of affairs is not good for radio and electronic engineering in Britain. Could they not persuade their Councils to allow them to get together informally to see if they can break the deadlock? If the problem had been tackled ten or even five years ago, only the Radio Section would have been involved in the IEE. Now a complicating factor is that the BritIRE covers a fair acreage of the ground of the IEE's Measurement and Control Section as well; it is, for example, establishing a Computer Group next month.

In one point at least the BritIRE's Council have the more liberal mind. They take the IEE publications in their library, while the IEE Council ban the BritIRE's *Journal* from Savoy Place. To me it is amazing that papers of the calibre of some of those presented at the 1957 Cambridge Convention on 'Electronics in Automation' are not available—for political reasons—in Britain's premier library of electrical engineering.

COMPUTERS often play light-hearted games with visitors to exhibitions and conversaziones. But in the Management Game, invented in America and recently introduced by IBM United Kingdom to this country, a computer has a serious role. The object is to help firms teach financial management to their employees—particularly middle executives who may be experienced in only one part of a company's work. Last month I spent a stimulating forenoon in Wigmore Street playing a shortened version of the game.

In it players are divided into three syndicates representing the boards of three competing companies which manufacture and market the same product. Each company has four areas to operate in: its own, the other two companies' and a common area. Transport costs vary according to area. A board receives market information for all companies' operation in the last three months, and confidential financial information for its own company. When the game begins, each board has to make decisions about plant investment, expenditure on marketing and selling price of the product in each area, etc., for its company in the coming quarter. Details of these are passed to a computer, which rapidly calculates the effects on assets, profits, etc, of each company at the end of the three months' trading. New figures are printed out and passed back to the individual boards. Then fresh decisions must be made again for the next quarter—and so on.

The three companies start on level terms. Even after two rounds, which is all we had time to play, it was exciting to see how profits and assets were varying, and to try to anticipate one's competitor's moves. I think our customers were winning against all three companies, but I understand this is common in the early rounds with newcomers to the game.

This technique, developed out of the 'war games', obviously has considerable training possibilities. IBM are hiring the equipment to companies, universities training colleges, etc, but they are not setting out to teach management themselves.

A CONTROL - CONSCIOUS friend of mine vouches for the following story. Last year he was visiting a large works making light alloys for the aircraft industry. At one point he and his guide came to a 10 ft rolling mill with eight men standing round the output side. He asked the reason for so many men, and was told that they threw off the badly rolled sheets. Rather puzzled, my friend was on the point of suggesting a suitable instrument when a door opened sharply at the far end of the shop. A curious old man popped his head through the opening and yelled, 'Foul sheet', whereupon the men moved forward and briskly threw a newly rolled sheet onto a reject pile. Turning to my mystified friend, the guide pleasantly explained 'That was Harry, the inspector. He's been here twenty years and can tell by its sound if a sheet has been rolled correctly'.

TWO readers sent me the correct solution to last month's puzzle: February and March 1984. The dates of publication are 2nd February and 8th March, differing numerically by 6, the only applicable perfect number. Both solvers brought in Orwell; the connexion is somewhat tenuous, but in devising the puzzle, 1984 seemed more significant as an answer than say 1980 or 1976. *Punch* has mournfully pointed out that we are now only 25 years off. Whatever the 1984 issues of NUCLEAR POWER are like, this month's issue (sent as a prize) is certainly a bumper one; it weighs over 2 lb and is ½ in. thick. I hope the two solvers enjoy reading it.

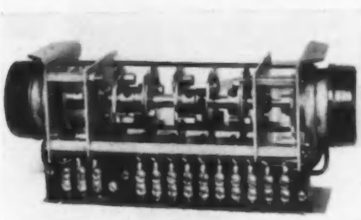
New for Control

A monthly review of system components and instruments

MULTI-CIRCUIT TIMER

can be driven in either direction

The Rodene Electrical Co Ltd have developed a new synchronous multi-circuit timer which can be driven clockwise or anti-clockwise. This is achieved by fitting two Rodene self-clutching motors. When one is energized it automatically clutches on to the camshaft and drives it in one direction unimpeded by the other motor which remains un-clutched. Similarly, energizing the second motor drives the camshaft in the reverse direction. The unit can have up to 24 fully adjustable twin cams, and was first produced to raise and lower the output of a set of pumps. It is also made with the two motors at one end (one being shaded to give reverse rotation), and with a variable resistor fitted to the free end of the camshaft which can be connected to re-balance a bridge when the correct number of heaters,



The timer can be fitted with up to 24 fully adjustable twin cams

pumps or the like have been switched on to give the rate of correction called for by the condition that un-balanced the bridge.

The sole distributors are D. Robinson & Co.

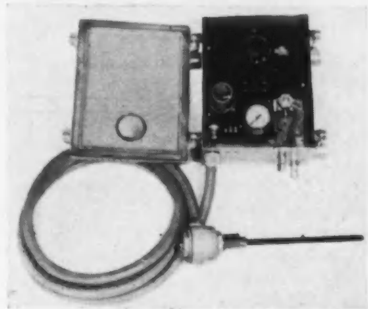
Tick **No 109** on reply card

LEVEL CONTROLLER

transistorized, robust

An on-off level controller from Fielden Electronics Ltd provides an output air pressure suitable for operating a standard pneumatic diaphragm control valve. Called the Pneutronic, it can be used for controlling the level of solids or liquids which may be at high temperatures, high pressures or under corrosive conditions. A robust electrode is the only item in the container and there are no components to become clogged or worn. The equipment is fully transistorized and operates from a supply of 12 V d.c. The air supply required is 17 − 20 lb/in² gauge.

A vertical electrode is mounted in the container whose level is to be controlled. When the tank is empty, this electrode has a



The control box and level probe

certain electrical capacitance to earth, but as the level of material rises the capacitance increases. This capacitance is used in an oscillator circuit and the relative values of the electrode capacitance and a variable condenser determine whether the circuit oscillates or not. The variable condenser is the control by which the operating level can be changed. When the material in the tank rises to the desired level, the circuit oscillates and a d.c. signal is fed to the converter, which consists of a small electrically-operated shuttle valve. This shuttle valve either allows air to pass to the control valve or reduces the control valve air pressure to atmospheric. When the material falls below the desired level, the d.c. signal is removed from the shuttle valve and the output air pressure is reversed.

Tick **No 110** on reply card

EQUIPMENT CABINET

aid to construction

One solution to the problem of housing the complex and varied equipment to be found in control engineering has been made by H & E Lintott Ltd. They have provided a cabinet whose components can be built up in a number of combinations to suit different wiring requirements. The cabinet (1 ft 11 in. wide by 2 ft 1½ in. deep and 5 ft 8½ in. high) is made of aluminium alloy on an angle frame with a casting top and bottom. This casting takes three standard drawers of an open frame construction into which the wiring assembly is dropped on its chassis and supported by side members. The drawers are 8, 12 or 16 in. high and can be used in any combination to give a total height of 48 in. Each is mounted on runners and can be latched in the closed, half-open or fully-open positions. The drawers have a detachable front panel which carries indicator lamps and fuses and the equipment has several other useful features.

Tick **No 111** on reply card

PLUG-IN UNISELECTOR

smallest ever?

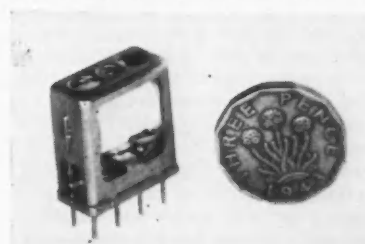
The plug-in uniselector switch manufactured by Siemens Edison Swan Ltd is claimed to be the smallest ever. It has 36 outlets and measures 3¾ × 2¼ × 1½ in., with a weight of 12 oz. The company say it will operate for two million revolutions without need for readjustment, and that it has a working life of at least eight million revolutions before replacement of any part. It is designed for operation in 22 or 50 V circuits in its standard versions and incorporates its own spark quench device.

Tick **No 112** on reply card

RELAY

stands severe usage

The hermetically sealed Clare F relay weighs 0·52 oz and measures 0·87 × 0·8 × 0·4 in. It has 2-pole double throw contacts rated for 3 A at 28 V d.c. and 115 V a.c. The pick-up time is 3·5 msec and drop-out time 1·5 msec. The nominal operating power is 250 mW. To meet military requirements, it has a temperature range of − 65 to + 125 deg C. Owing to the balanced armature construction, the rigid frame and high contact forces, it will stand severe continuous vibration, and survive a shock of 65 *g* for 11 msec. Production is to be initially concentrated on the 26·5 V model having



Small though it is the relay can survive 65 *g* for 11 msec

a minimum operating current of 19 mA and a coil resistance of 675 ohms. The relay is designed for $\frac{1}{10}$ in. grid printed circuits. The relay is made by C. P. Clare Ltd (another member of the wide-spread Elliott-Automation group) under licence from C. P. Clare & Co of the USA.

Tick **No 113** on reply card

FUNCTION FITTER

self-contained, versatile

A non-linear computing component, the model FF function fitter, from Philbrick Researches Inc, is a self-contained unit for the simulation of arbitrary functions of the

input voltage. It features 10 straight line segments with adjustable tangent parabolic rounding, and adjustable slopes, break points are adjustable to permit greater accuracy in regions of large slope change, and the incremental slopes are adjustable over a range greater than ± 10 : 1. The unit is mounted on a 10½ in. rack panel, uses 100 mA at ± 300 V, and about 80 W at 115 V a.c.

Tick **No 114** on reply card

ELECTRIC RELAYS
interlocking and plug-in types

A recent interlocking relay (series 593) has been designed for switching between alternate circuits at regular or irregular intervals. The unit comprises a pair of relays that are mutually interlocking so that one or the other is always locked in. Either or both coils can be supplied for a.c. or d.c. operation and either or both relays may carry multiple contact assemblies. The contact rating is 5 A at 30 V d.c. or 250 V a.c. resistive, with a maximum nominal coil voltage of 140 V d.c. or 250 V a.c.

A pair of relays that are interlocking so that one or other is engaged

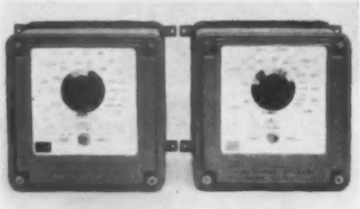
A plug-in version of the P.O. type 3000 relay (series 305) is also available, either enclosed or hermetically sealed. The relay is mounted on a 8, 9 or 11 pin octal style header and can be supplied complete with socket. Available for all standard d.c. coil voltages and with double-pole normally-open or double-pole normally-closed heavy duty contacts or double-pole changeover light duty contacts.

The two relays are made by Magnetic Devices Ltd, who have also introduced a number of a.c. and d.c. relays mounted on screw terminal bases.

Tick **No 115** on reply card

ELECTRONIC PROCESS TIMERS
six basic models

A new series of electronic process timers has been added to the range of equipment already produced by Lancashire Dynamo Electronic Products Ltd. The new units (series PCT.1) are available in six basic forms depending upon the required time range, and can be connected together to provide multi-stage timing control for complete processes. The six basic models are designed to provide time ranges of 0·1 to 1·5, 0·3 to 5, 1 to 15, 3 to 50, 10 to 150 and 30 to 500 secs. Each main time range is subdivided into long and short ranges, selected by a switch, and a continuously variable control is provided for accurate setting of the required time interval. The units have a repeat accuracy of ± 1%, and variations in supply voltage of − 15 to + 10% will not cause more than ± 5% change in the set time interval. The timers are designed for 200/250 V or 110/115 V 50/60 c/s.



Two of the timers, showing the maximum and minimum ranges available

Tick **No 116** on reply card

TEMPERATURE TRANSMITTER
uses high purity helium

The latest version of the Sunvic pneumatic temperature transmitter uses high purity helium as a filling gas in the thermal system. Sunvics say that they selected helium for several reasons. Firstly, it is chemically inert, and damage to the bulb can have no adverse effect on a process, even in the case of explosives or food. Secondly, the thermal conductivity of helium is good, ensuring rapid response of the instrument to changes in temperature. Moreover, use of helium makes it possible to test the complete thermal system in a mass spectrometer, so that even the most minute leak can be unerringly detected. This ensures excellent long-term stability combined with the fact that the thermal system is filled at comparatively low pressure, so that volumetric changes of the bulb at high temperatures are reduced to a minimum. The system is inherently linear as it is a constant-volume thermometer, and does not permit any changes in temperature.

Tick **No 117** on reply card

ELECTRIC RELAY
with variable contacts

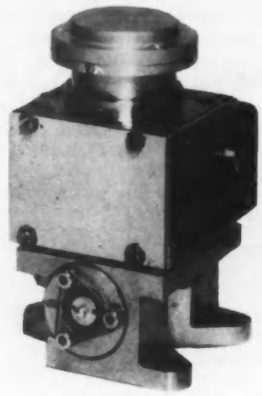
A new relay has recently been introduced with variable contacts which can be set to operate at any of a number of given positions. It can be used to operate a slave relay and will carry a maximum of 30 V d.c. A recommended slave circuit would be equivalent to a 5000 ohm Post Office 3000 type relay working on 30 V and with a germanium rectifier across a coil acting as spark quench. The relay can be supplied with a resistance of a fraction of an ohm to thousands of ohms, is fitted with a plug-in base and has floating bearings. The relay is manufactured by A. P. Besson & Partner Ltd and the sole selling agents in Great Britain are Westool Ltd.

Tick **No 118** on reply card

ADJUSTABLE LAP VALVE
settings to within 10^{-4} in.

The Elliott adjustable lap hydraulic control valve is claimed to have numerous applications for hydraulic servomechanisms in both aircraft and industrial fields. The adjustable lap system enables a high degree of linearity to be achieved, while lap settings can be adjusted to within 10^{-4} in. with the valve *in situ* and in operation. Pressure ranges are available up to 4000 lb/in.^{2} At 3000 lb/in.^{2} maximum rated flow is 120 cm^3/sec. The total weight of the unit is 1·7 lb.

The frequency response on open-loop conditions is flat within 1 dB up to 100 c/s and within 3 dB up to 300 c/s. An Elliott a.c. pick-off is a composite part of the valve and can be used on closed-loop applications or for monitoring purposes. In addition various ranges of torque motor input impedances may be selected. The range of Elliott miniature 5 W and 9 W 400 c/s magnetic amplifiers includes units suitable for driving the valve. A transistorized pre-amplifier is also available.

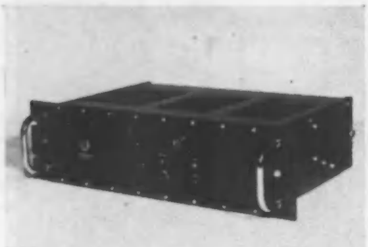


Adjustable lap on this control valve enables a high degree of linearity to be achieved

Tick **No 119** on reply card

MULTI-CHANNEL SUMMATOR
counting rate of 1200 pulses/sec

The multi-channel count summator (type 132A) has been designed by the Instrument Division of Ericsson Telephones Ltd. The sources (up to 12) can be random with respect to each other and the counts on each line can be random provided that the minimum separation is not less than 10 msec. Thus the maximum summating rate possible is from 12 sources each of which provides output pulses at a periodic rate of 100 pulses/sec, representing a total counting rate of 1200 pulses/sec. The summator is



A summator for use where the outputs from up to 12 sources are required to be counted into a single channel

constructed from plug-in sub-units, and can be provided to summate any number up to 12.

Each input feeds a separate bi-stable store circuit, which utilizes cold cathode trigger tubes as the storage elements. A second input to the store is connected to one cathode of a Dekatron selector. The stores are sequentially scanned at a pre-set frequency and if an input pulse is present the clearance pulse from the Dekatron on the second input clears the store, and passes the stored input on to a shaping output circuit. Each store is cleared in turn, resulting in a train of pulses being passed to the output. Clearance of a store automatically prepares it for the reception of a further pulse.

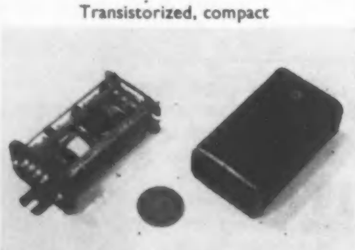
Tick **No 120** on reply card

SERVO AMPLIFIER

overall power gain of 72 dB

A new fully transistorized servo amplifier can give its rated output at ambient temperatures up to + 90 deg C without the use of a heat sink. The unit has been primarily designed to operate with a specific servomotor (type 15b), and its output stage is such that a controlled measure of viscous damping is introduced to the motor. The input signal passes through a limiter to a three-stage RC-coupled amplifier, followed by a driver-stage transformer connected to a power stage operating in the single ended class A mode. The load is autotransformer connected to the power stage. The basic amplifier has an overall power gain of 72 dB when the source impedance is not less than 250 ohms. It is designed for a carrier frequency of 400 c/s and has a consumption of 12 W at 36 V d.c. A transistorized power pack for supplying two of the servo amplifiers has been designed to operate from 115 V 400 c/s and is capable of delivering up to 30 W at 36 V d.c. The regulation is better than 8% and the ripple voltage is less than 0·5% with a 50 μF parallel capacitor.

Transistorized, compact



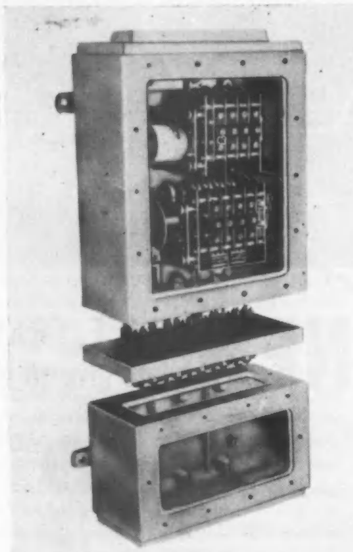
The servo amplifier and power pack are made by S. G. Brown Ltd.

Tick **No 121** on reply card

QUICK LOOKS

Electrical Remote Control Co Ltd have informed us that their whole range of automatic, continuously cycling cam-operated and hand-set process timers, multiple contact and mercury relays is now available in flameproof enclosures. The enclosures are certified in Buxton Groups II and III.

Tick **No 122** on reply card



One of the Elremco timers in a flameproof enclosure

A range of eight photomultiplier tubes for scintillation counting and industrial applications is to be introduced by Mullard. The range comprises one 15-stage and two 10-stage tubes.

Tick **No 123** on reply card

A new range of thermistors (thermally sensitive resistors) has been introduced by The Plessey Co Ltd for temperature measurement and the control of thermal drift in electrical circuits. They can also be used for the measurement of ultra-high frequency power, voltage regulation and relay timing.

Tick **No 124** on reply card

Lindars Automation Ltd have recently developed a combined events per unit time and time per unit event counter. Basically the unit consists of an electrical preset counter, an electrical resetting counter and a 1 rev/sec synchronous motor giving 10 impulses/rev. The required time may be set on the presetting counter up to a maximum of 999·9 sec and at the finish, the number of events will be displayed on the resetting counter.

Tick **No 125** on reply card

A new range of a.c. motor control gear has been introduced by Lancashire Dynamo Nevelin Ltd. For direct-on starters up to 60 h.p. and star-delta starters up to 100 h.p. a vertical lift block type contactor is employed in conjunction with a range of ambient temperature compensated thermal overload units.

Tick **No 126** on reply card

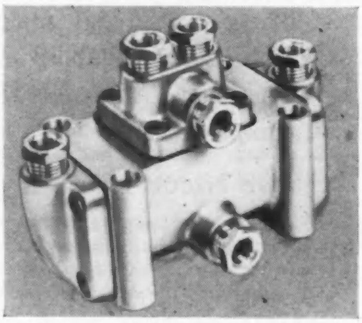
A clock type counter box has been designed by Devon Instruments Ltd as a revolution counter for tape recorders. The drive unit comprises a worm, wheel and flexible shaft. The box is reversible, zero setting, and gives a reading up to 1000 revolutions of the drive motor.

Tick **No 127** on reply card

Two stationary Hydrovane air compressors have been added to the range manufactured by Alfred Bullows & Sons Ltd. The first of these (200SR9501) has an output of 95 ft³/min at 100 lb/in² and is mounted on a 6 × 2 ft horizontal air receiver. The second unit (250SR12001) has an output of 120 ft³/min at 100 lb/in².

Tick **No 128** on reply card

The latest product from Lang Pneumatic Ltd is a totally enclosed double air-operated 4-way automatic valve. The ports are a full ½ in. The valve is of the linear slide type, having the operating shuttle and valve made from stainless steel. With 80 lb/in² in the valve chamber the pressure required to operate the pistons is 15 lb/in².



A 4-way valve operating on 15 lb/in²

Tick **No 129** on reply card

An air blower from Pullin delivers about 15 ft³ air/min against a back pressure of 0·7 in. water gauge. It draws 0·5 amp at 24 V d.c. and is claimed to have an operating life of over 1000 h.

Tick **No 130** on reply card

In the December issue the working pressure of the Kent-Barton instrument mentioned in *New for Control* should have read 2500 lb/in².

PEOPLE IN CONTROL

by Staffman

O. P. MEDIRATTA
A passage to India

J. R. PICKIN
Moves in

P. D. HALL
Moves on

A. S. MARSHALL
To ease the strain

H. G. NELSON
A tighter hold

B. W. Pollard's resignation from the post of computer manager at Ferranti has led to 'general post'. Electronics manager **P. D. Hall** steps into Pollard's shoes and is himself replaced by microwave engineer **J. R. Pickin**. Peter Hall tells me that he is new to computers—semiconductors apart, his electronics background has for some time been concerned more with bread-and-butter electronics than with embryo products. He sees the Ferranti computer job as a stimulating challenge.

The Electronic Engineering Association represent a very healthy and expanding section of British industry and consequently find themselves busy these days. One result of this pressure is the appointment of **A. S. Marshall** to the post of deputy to **H. E. F. Taylor**, the EEA's secretary. 'Absolutely delighted' was Marshall's comment on his new position.

Cecil Dotson becomes Texas Instruments (Bedford) chairman in succession to **P. E. Haggerty** who remains president of Texas Instruments Inc, the American parent company. **Dudley Saward**, MD of Texas in Bedford, tells me that the idea is to increase on-the-spot managerial strength. I gather that a new and larger plant is planned for Bedford. Incidentally, they have reduced the prices of their silicon semiconductors yet again, some by as much as 35%.

It was amusing to hear **G. G. Gouriet**—now with Wayne Kerr (ex BBC television research)—evading leading questions at a recent press conference. Press-men wanted him to say he had left the BBC in a huff because of differences over colour television. The real reason is, apparently, rather less dramatic. As Gouriet said 'TV was fun, but . . .'

H. G. Nelson, English Electric's MD, has been appointed deputy chairman of EE subsidiaries: Napier, Marconi's Wireless, Marconi Instruments, EE Valve, Vulcan Foundry, Robert Stephenson and Hawthorns and of the associated company Marconi International Marine. H. G. is, I gather, known affectionately in the EE Group as Half-Nelson.

E. M. Butterworth has left Magnetic Devices to become Besson & Robinson's chief engineer. He tells me that BR are adding some interesting new relays to their already comprehensive range.

Audley Engineering's sales director **F. E. Varlow** is responsible for their new department handling Audco Annin control valves. The department manager is **R. C. Archbold**. Varlow said 'We manufacture the premier lubricated taper plug valve in Europe and I have high hopes for the Audco Annin range which has proved so successful in North America.'

I hear from **Dr O. P. Mediratta** that he has left Short Brothers & Harland, where he was head of the guidance and control department for GW, to take up an important post in India. He becomes Deputy Director (R and D), Directorate of Technical Development and Production (Air) in the Indian Ministry of Defence.

LOOKING AHEAD

A diary for the next three months

Unless otherwise indicated, all events take place in London. BCS British Computer Society. BritIRE British Institution of Radio Engineers. IEE Institution of Electrical Engineers. IMechE Institution of Mechanical Engineers. RAeS Royal Aeronautical Society. SIT Society of Instrument Technology

MONDAY 12–WEDNESDAY 14 JANUARY
5th National Symposium on Reliability and Quality Control in Electronics (See *Looking Ahead* October)

WEDNESDAY 14 JANUARY
Symposium on Storage Media SIT 6.00 at Manson House, Portland Place, W1

FRIDAY 16 JANUARY
Inherent Non-linear effects in Hydraulic Control Systems with Inertia J. K. Royle *Response of a Loaded Hydraulic Servomechanism* D. E. Turnbull IMechE 6.00 at the Institution

MONDAY 19 JANUARY
Study of the Applications of a Computer to Production Control D. C. Hemy BCS 6.15 at the Northampton College of Advanced Technology, EC1

MONDAY 19–THURSDAY 22 JANUARY
Physical Society Exhibition Royal Horticultural Society's Old and New Halls, Westminster (see pp 58–62)

TUESDAY 20 JANUARY
D.C. Amplifiers Discussion opened by K. Kandiah IEE 5.00 at the Institution

MONDAY 26 JANUARY
Automation (Faraday Lecture) H. A. Thomas IEE 6.00 at the Royal Festival Hall Admission by ticket

TUESDAY 27 JANUARY
Symposium on Flow Measurement SIT 6.00 at Manson House, Portland Place, W1

WEDNESDAY 4 FEBRUARY
Inaugural Meeting of Computer Group BritIRE 6.30 at the London School of Hygiene and Tropical Medicine, Keppel Street, WC1

WEDNESDAY 11 FEBRUARY
Digital Instrumentation System for use in the Testing of Jet Engines L. Airey SIT 6.00 at Manson House, Portland Place, W1

MONDAY 16–TUESDAY 17 FEBRUARY
Specialist Discussion Meetings on new Digital Computer Techniques Committee of the Measurement and Control Section IEE At the Institution

TUESDAY 17 FEBRUARY
Simulation of Melting Shop Operations on a Computer R. Neate BCS 6.15 at the Northampton College of Advanced Technology, EC1

THURSDAY 19 FEBRUARY
Theoretical Studies of Guided Missile Control Systems E. G. C. Burt RAeS 6.00 at the Institution of Civil Engineers, Great George Street, SW1

TUESDAY 24 FEBRUARY
Symposium on Automatic Weight Control in Industry SIT 6.00 at Manson House, Portland Place, W1

THURSDAY 5 MARCH
Symposium on the Use of Data Recorded on Industrial Plant SIT 6.00 at Manson House, Portland Place, W1

WEDNESDAY 18 MARCH
Approach to Learning and Teaching Machines C. E. G. Bailey BCS 6.15 at the Northampton College of Advanced Technology, EC1

MONDAY 6–THURSDAY 9 APRIL
16th Annual Radio and Electronic Component Show organized by the Radio and Electronic Component Manufacturers' Federation to be held at Grosvenor House and Park Lane House, W1 Admission by invitation only

LOOKING FURTHER AHEAD

WEDNESDAY 29–THURSDAY 30 APRIL
Convention on Thermonuclear Processes IEE At the Institution Further details from the Secretary

MONDAY 11–WEDNESDAY 13 MAY
Joint Symposium on Instrumentation and Computation in Process Development and Plant Design (See *Looking Ahead* November) Further details from the General Secretary, Institution of Chemical Engineers. Applications by 30th January, 1959

THURSDAY 21–WEDNESDAY 27 MAY
The International Convention on Transistors and Associated Semiconductor Devices, noted in *Looking Ahead*, August, is now to be held from 21–27 May, 1959, not 25–29 May. There will be a technical exhibition associated with the Convention

MONDAY 22–THURSDAY 25 JUNE
1st British Computer Society Conference at Cambridge

For your bookshelf

Bits and words

High Speed Data Processing** by **C. C. Gotlieb** and **J. N. P. Hume
McGraw-Hill. 1958. 338 pp. £3 14s. ★ **156**

As this book's preface says 'since all three aspects of data-processing are considered—machine description, programming methods and applications—it necessarily follows that the treatment is elementary'. This is both the book's strength and its weakness. Essentially the book is an introduction to programming. There is considerable need for such books: those available to potential machine users are mostly either very advanced, or else written in the context of one machine.

'High Speed Data Processing' only in part satisfies the need. It is not advanced, nor does it dwell on one machine. It is, however, rather wordy, it calls for rather too much knowledge, and differences and likenesses of possible machines are not sufficiently brought out. By over-simplifying it sometimes misleads. It gives a 'simple payroll programme' of twelve instructions (a typical payroll programme might have 5000). It shows how to calculate computing time, given a complete programme, when the real problem is how to estimate the time, without making the complete programme.

The authors have included a fairly full section on sorting techniques for use with computers, and sketchy ones on the uses of computers in insurance and accountancy. There is a short chapter on automatic programming techniques, and a useful, but very elementary, introduction to machine use in scheduling and planning work. The book contains much useful information about American computing devices, but devotes only a line or two to British ones—maybe because the authors' knowledge of them is small. E. A. NEWMAN

Swash and wobble

Control System Components** by **J. E. Gibson** and **F. B. Tuteur
McGraw-Hill. 1958. 502 pp. £4 13s. ★ **157**

The subject of automatic control has become of immense importance and since the war there have appeared about a hundred or so textbooks on the theory of such systems. This has become generalized and dissociated from any particular hardware; nevertheless recent advances in control engineering show the development of elements specifically designed for this type of work. Basically these elements, for example the potentiometer, are by no means new, but the trend for low inertia, accuracy, minimum friction and reliability has produced devices very different from their predecessors. This book describes in detail the more commonly used components of control systems. It assumes a basic knowledge or familiarity with the subject of control.

The first chapter, alleged to be for the purpose of introducing the notation, goes rather rapidly through electric network theory and does not really seem attached to the remainder of the book. The control elements fall into easy grouping and we find two chapters on electronic devices, four on electromechanical, including d.c. and a.c. machines, and two chapters each on purely mechanical, hydraulic and pneumatic systems.

In the purely mechanical section there is a good treatment of gyroscopes of the variety used for control and inertial navigation. One is surprised to find no mention of angular accelerometers, although linear acceleration measurement is adequately covered. On the electronics side the treatment of phase discriminators is outstanding.

The nomenclature, though American, is fairly standard and always understandable. It is amusing to find that a 'swash plate' becomes a 'wobble plate' on crossing the Atlantic.

The book is useful to control engineers and most timely. The exposition is clear with good diagrams. J. C. WEST

To and from Russian—electronically

English-Russian Russian-English Electronics Dictionary
McGraw-Hill. 1958. 943 pp. £3 2s. ★ 158

A dictionary of electronics as voluminous as most of the existing Russian-English scientific dictionaries cannot fail to impress. However its title is something of a misnomer, for not only does it treat the subject of electronics as generally understood, but provides a very fair coverage of related fields such as telegraphy, telephony, radar, and telemechanics, which includes telemetering and telecontrol. The book was produced originally in 1956 on behalf of the US Department of the Army, but neither of the long lists of published sources used in its compilation gives any reference to service glossaries. The numerous IRE glossaries of standard terms in electronics and radio engineering published between 1948 and 1955 have been used freely, but the only authoritative British sources quoted are the BSI glossaries for electrical engineering and telecommunication of 1943. The Russian vocabulary has been derived mostly from standard textbooks in the electronic field and from four technical journals only.

A pleasing feature of the dictionary is the way it covers compound terms and phrases, such as *grid-controlled mercury arc rectifier*, *jamming homing set*, and so on. Very welcome too is the introduction of what are described as reference 'clusters'. If we look say under *junctions* in the English-Russian section, we are cross-referred to some forty other compound terms involving the word 'junction', *hole-emitting junction*, *slit-coupled junction*, etc, the same scheme applying of course to the Russian-English section.

This is a work which might well be emulated in other branches of science. Nor indeed is the need for comprehensive dictionaries of this sort confined to Russian, for there seems to be nothing comparable with it even in the more commonly known Western European languages. G. N. J. BECK

Planung und Projektierung automatisierter Anlagen *by* **Rolf Hofmann.** *Hamburg. Decker's Verlag, G. Schenck. 1958. 208 pp.* ★ 159

This book examines the general problems of the planning and realization of automatic manufacturing equipment; it is chiefly valuable for its consideration of the financial and economic questions involved, although the social consequences are also touched upon. The techniques themselves, mechanical or electronic, receive but brief mention. The main discussions are in terms of 'transfer' machines and little is said of numerical control, and although the possibility of making use of computers for process control is suggested, no concrete examples are given. The book is illustrated by photographs of representative machines. A. O. STANESBY

Books received

Position Control of Massive Objects. A. Tustin *et al.* Institution of Electrical Engineers. 1958. 64 pp. 15s. 0d. ★ 160

Theory and Design of Magnetic Amplifiers. E. H. Frost-Smith. Chapman & Hall. 1958. 506 pp. £3 15s. ★ 161

Introduction to the Design of Servomechanisms. J. L. Bower and P. M. Schultheiss. John Wiley: New York. Chapman & Hall: London. 1958. 522 pp. £5 4s. ★ 162

Flow Measurement and Control. W. F. Coxon. Heywood & Co. 1959. 322 pp. £2 15s. ★ 163

Economic Operation of Power Systems. L. K. Kirchmayer. John Wiley: New York. Chapman & Hall: London. 1958. 268 pp. £4 16s. ★ 164

Lindsay's International Register of Wire and Rod Strip. 1957–1958. Lindsay's Wire Publications. 247 pp. £1 5s. ★ 165

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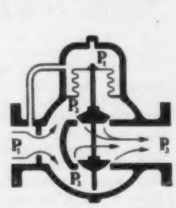

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